Hydrographic Surveying

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Hydrographic Surveying.

Methods, Tables and Forms of Notes.

BY

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GENERAL

TABLE OF CONTENTS.

PART I.

Hydrographic Surveying.

PART II.

Measurement of Stream-Flow.

PREFACE.

In offering this Manual to the public, the author ventures to hope that the information contained herein may be useful to engineering students and to the younger members of the profession as well as to those engineers of larger experience who are not thoroughly familiar with the minor details of Hydrographic Surveying.

The author is conscious of the fact that much of the matter contained in the manual is elementary and that the hydraulic formulas are stated as nearly as practicable in their simplest forms. While this is true, it is believed that the subject under consideration, hydrographic surveying, does not require profound discussion, and that plain, direct treatment of the subject matter will be productive of the best results.

No attempt has been made to introduce complicated mathematical formulas into the text since it is believed that ultra refinement in a hydraulic formula for discharge would be out of place in view of the impossibility of making ordinary field measurements with microscopic exactness. It has not been thought necessary to go deeply into theoretical or scientific derivations of causes and effects of phenomena connected with the flow of water. Such matters are fully covered in works on hydraulics, of which there are a number of excellent examples.

It is the author's purpose to explain the practical features of hydrographic surveying, such as are likely to be encountered by the surveyor in actual practice and such as are at present to be learned only by actual field experience in this class of work. Much of the information contained in this manual was acquired by the author in the course of his professional work, and consequently has the merit of practicality.

The author has endeavored to limit the scope of this manual to such ordinary methods of hydrographic surveying as are likely to come within the practice of the hydrographic surveyor. It is desired that this little book will consitute a practical paper on surveying as applied to hydrographic work, and to embody therein a concise explanation of modern methods of practice.

SAMUEL H. LEA.

New York, October, 1904.

PART I.

HYDROGRAPHIC SURVEYING.

CHAPTER I.

OBJECT—OUTLINE SURVEYS—TRAVERSE SURVEYS—CONDUCT OF SURVEY—TOPOGRAPHIC SURVEY—OTHER METHODS—CALCULATING CAPACITY—SURVEY OF SUBMERGED AREA.

Definition. The term Hydrographic Surveying is applied to surveys of rivers, lakes, canals and other bodies of water. Under this head should be included surveys of water sheds and drainage areas; also surveys of basins or reservoirs for the storage of water on a large scale.

Object. Hydrographic surveys are usually made for one or more of the following purposes:

1. To determine the outline of a body of water, or of a water shed, basin or storage reservoir, in order to obtain sufficient information from which to prepare an outline map of the area surveyed, and to calculate the extent of the area covered.

2. To determine the dimensions and the physical characteristics of a storage basin or reservoir in order to calculate its storage capacity.

3. To determine the elevations of a sufficient number of points in a submerged area to define the sub-aqueous contours of the containing valley or basin.

4. To determine the discharge of a river or stream and to acquire such information as may be required concerning its physical characteristics.

It is evident from the foregoing that much of the field work connected with hydrographic surveying is identical with that required in making ordinary land or topographic surveys, and is consequently more or less familiar to engineers and surveyors in general. It is not the object of this manual to describe such work in detail; the object is rather to describe and explain such details of hydrographic surveying as are not so generally familiar, but which are necessary for the proper execution of the work.

Classification. The various operations connected with hydrographic surveying may, for convenience, be classified under the following heads: 1. Outline Surveys; 2. Topographic Surveys; 3. Surveys of Submerged Areas; 4. Measurement of Stream Flow. These operations will be discussed in order.

OUTLINE SURVEYS.

There are several kinds of outline surveys, which may be classified, according to the object for which made, in three divisions as follows:

a To determine the outline of a body of water of moderate size, as a small lake, a river, or a canal.

b To determine the boundary of a large body of water, as a bay, a great lake, or a large river.

c To define the limits of a drainage area or of a storage reservoir, a valley, or a basin.

The kind of surveys that are best adapted for the purposes mentioned will be discussed and their details explained.

TRAVERSE SURVEY.

An outline survey of a body of water of moderate size may be conducted as an ordinary traverse, using such field methods as are best suited to the case; such surveys are usually made with transit and chain.

When making a survey of this kind, in order to obtain good results, the transit points should be marked with hubs, accurately centered, careful fore and back sights should be taken, and the angles should be read on the vernier to the nearest minute. The courses should be run at a convenient distance from the water and the position of the water line determined by measurements from the line of the survey. The position of the high water line, when required, should also be determined and noted. The details of the local topography should be noted with more or less minuteness, depending upon the importance of the work. Prominent objects on shore, that are within convenient reach, may be located by direct measurement. Objects that are inaccessible or at a considerable distance from the survey, may be located by triangulation, as in the case of land surveys, sights being taken to each such object at two or more transit stations from which the object is visible.

Notes. The notes for a survey of this kind are kept in the same manner as for an ordinary traverse survey on land. In Form 1 is

shown the form of field notes of an outline survey of a lake, made under the author's supervision. In this survey a transit and 100-ft. steel tape were used. The angles were read on the vernier, and the magnetic bearings of the courses were noted. The survey was a little over 12 miles in length; the number of courses was large as the shore line was very irregular, requiring numerous angles. The survey was closed at the point of beginning; the transit was then set up over this point, a backsight was taken to the last transit point, and the angular measurement between the first and last courses was made, in order to re-determine the bearing of the first course. This was compared with the first observation made, at the beginning of the survey, and the difference was found to be 0° 12′. This difference is within the limit of allowable error for a survey of this kind and extent; such error should not usually exceed 0° 15′.

Party. The field party for a survey of this kind should be about the same as that required for an ordinary traverse on land or for a railroad survey. It is usually a good plan to provide, in addition to the regular sized party, two tapemen for making side measurements to locate the shore line and the local topography. When such addition is made the full party will consist of a transitman, a front chainman, a rear chainman, two tapemen, one or more axemen, and a back flagman. On important surveys an engineer in charge will be required, in addition to the full party mentioned. On small surveys or in cases where local conditions will permit, the engineer in charge frequently acts as transitman.

Outline of Storage Basin.

A transit traverse to determine the outline of a storage basin or reservoir is conducted in a somewhat different manner to that just described. In making a survey of this kind it is first necessary to determine the location of the flood line, sometimes designated as the flow line. This is a contour line at the height of the proposed surface of the impounded or stored water; it is fixed by the height of the storage dam, being at the same elevation as the spillway or overflow of the dam. When the dam is designed for overflow over its entire length the elevation of the crest of the dam is taken as the elevation of the flow line. The location of this line on the ground around the perimeter of the proposed basin or reservoir fixes the limits of the basin and is the object of the survey. In order to accomplish this object it is necessary to have a level party to designate the position of the flow line on the ground, in addition to a transit party to determine its location.

Conduct of Survey.

In making a survey of this kind the level party should keep abreast of or slightly ahead of the transit party in order to indicate the position of the flow line on the ground. The line of the survey is run as close as practicable to the flow line, side measurements being made thereto when necessary.

Party. The transit party should be about the same as for a lake survey. If care is exercised in fitting the survey line to the flow line the side measurements will be short; they can then be estimated or made by the level party or by the chainman, and in such cases no tapemen will be required. In many cases, however, it will be the part of economy to provide two tapemen for making side measurements to the flow line, as in the case of a lake survey for determining the shore line. When this is done the work will be facilitated and the general progress of the party accelerated.

The level party should consist of a leveller and a rodman. Since in a survey of this kind there are no variations in elevation to overcome, the work consisting in following a contour line, the level party should experience but little difficulty in keeping up with the transit party.

In a wooded or brushy country it is good practice to provide a sufficient number of axemen to facilitate the progress of the survey. It is economy always to have plenty of help, especially of the cheaper grade, on a survey party, since by this means it is practicable to accelerate the general progress of the survey and thus lessen the total cost of the work.

Stadia Surveys.

It is frequently the case that outline hydrographic surveys can be made with the transit and stadia with satisfactory results. In such cases the method of procedure is entirely similar to that followed in making ordinary stadia surveys. The stadia stations are established at suitable points along the boundary of the area to be surveyed. Details of topography and the configuration of the shore line, in the case of a body of water, or of the flow line in the case of a reservoir, are determined by side shots.

Other than stadia methods are frequently employed for making surveys of this kind; such methods are the same as those in use for land surveys where the conditions are similar. In many cases the plane table can be used to advantage, especially in filling in topographic details; this instrument has been much used by the engineers of the U. S. Coast and Geodetic Survey for work of this nature.

Where great accuracy is not required, a compass traverse will often prove entirely satisfactory for making outline surveys of bodies of water. In surveys of this nature the distances are measured with a 100-ft. chain and the bearings are read with the needle, as in the case of an ordinary compass land survey.

Triangulation Surveys.

Surveys to determine the outline of a large body of water, as a great lake, a large river, a bay, etc., are generally best made by triangulation. In such cases the methods usually employed for triangulation work are followed; those best adapted for the work in hand should be used.

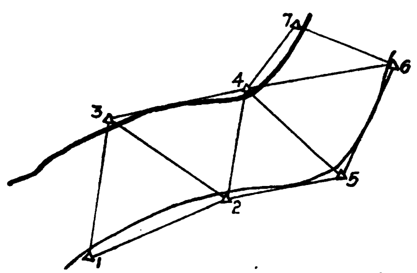

Fig. 1. Triangulation of River.

A good method of triangulating a river of considerable size is illustrated in Figure 1. A base line, as 1-2, is first carefully measured with a steel tape, the extremities of the base being marked with stout posts or hubs, carefully centered. All the other points and distances on both sides of the river are determined by angular measurements, the transit occupying successively the different triangulation stations; the distances between stations are calculated by trigonometry. When such a survey is of considerable extent it is usually a good plan to measure the final course, as 5-6, with a steel tape as a check upon the accuracy of the instrumental work. In order to obtain good results each observed angle should be measured not less than three times, the mean of the several readings being taken as the true reading.

Stadia Work. In a survey of a river, where the distance between opposite banks is not too great, stadia methods can be used to advantage, in connection with triangulation or traverse surveys. In such a case a good method to follow for such work is to run a transit line down one bank of the river, the distances between stations being carefully measured with a steel tape and the angles at all deflection points being repeated in order to guard against possible error. Points on the opposite bank can be located by intersection, the distances being determined by stadia. In this way fairly accurate results can be obtained at moderate expense.

Topographic Surveys.

Surveys made to determine the topographic features of a watershed or drainage area, or of a reservoir site, are essentially topographic surveys and, as such, require no extended treatment in this manual.

In modern practice stadia methods are extensively used in surveys of this nature; many of the United States Deep Waterways surveys were made with transit and stadia. In the United States Deep Waterways topographic surveys on the Black and Salmon rivers, conducted by Mr. W. B. Landreth, Member American Society Civil Engineers, and described by him in the Transactions of the American Society of Civil Engineers, the methods used were both simple and effective. The following account of these surveys is taken from the description above referred to; it is cited as a good example of modern practice for such work.

Party and Outfit. The party consisted of the engineer in charge, a transitman, a recorder, three or more stadia rodmen, a draftsman, a computer and two or more axemen. When running levels the head stadia rodman was detached from the main party for that purpose.

The outfit consisted of a transit, fitted with stadia wires, its horizontal limb reading to 20 seconds, and its vertical arc to single minutes; a stadia rod for each rodman, a wye level and level rod, a large canvas umbrella, a tin megaphone, a 100-ft. steel tape, and the necessary outfit of drawing table, instruments, etc. This equipment is the same as that ordinarily used for a survey of this nature, with the addition of the umbrella and the megaphone. The former is quite useful for protecting the observer and his instrument from the weather; it is not commonly used, however, in ordinary surveys. A megaphone is serviceable in transmitting directions from the observer to other member of the party; it is a modern innovation and has not come into general use.

Field Work. The field work was conducted in the manner usually adopted on surveys where distances are determined by stadia. The engineer in charge selected the base line points to be occupied, and located the stadia points on circuits, so arranged as to cover the territory fully; the party followed closely behind. Each stadia rodman was assigned a particular class of objects to locate; one followed the streams, another selected contour points, another located roads, buildings, woods, etc. The rodmen all worked independently of each other; when convenient all were kept on the same

side of the transit in order to facilitate the reading and platting of the azimuths.

When working on streams of considerable size a circuit was run along one bank and the topography on both sides of the stream was taken therefrom. In doing this the corps of rodmen was divided into two parties, one party being kept on each side of the stream during the observations. In surveying a large stream that was frozen over, a circuit was run on the ice and the topography on both sides was located therefrom.

The topography of crooked streams, that were not frozen, was located by means of a circuit which was run so as to cross the stream at the bends and to include as much of the adjacent topography as possible. In such a case part of the rodmen worked on each bank and the remainder of the party crossed the stream from point to point as the survey progressed.

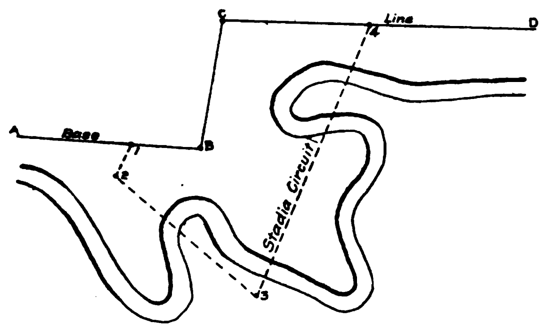

Fig. 2. Stadia Survey.

This method is illustrated in Fig. 2, in which the full line A, B, C, D represents the base line and the dotted line 1, 2, 3, 4 represents a circuit.

Wooded areas were surveyed by methods suited to the local topographical conditions. For deep hollows or gorges a circuit was run along the top of each bluff, the slope on either side being taken from the line on the opposite bluff. For long, gentle slopes a circuit was run along the top and the foot of each slope, and short circuits were run connecting them, so spaced as fully to cover the territory surveyed.

All streams, roads, buildings, outlines of woods, town and county lines were located. Two corners of each building were generally located by the observer, the rodman measuring the dimensions with his rod and giving the data to the recorder when passing him.

Office Work. At the close of each day's field work the field party reduced and checked the stadia readings made during the day, also the vertical angle elevations. The office force calculated the latitudes and departures of the stadia circuits. Two or more field books were in use at one time, the recorder changing books each

day, and leaving the book used in the field on the previous day for use of the office force.

In the instance that has been cited the size of the party was greater than is ordinarily used for making surveys of this kind. When rapid work is required and the office work is to be kept up with the field work, it is advantageous to have a large party. Usually, however, in surveys of this nature, a stadia party consisting of five men will be of sufficient size. Such a party should consist of an instrument man, a recorder and three rodmen. When required, one or more axemen or laborers should be added to the party, for cutting brush, rowing a boat, etc. A party of this size, with no office force, will not be able to keep the field notes written up and the reductions made by evening work. It is, therefore, advisable to take advantage of stormy days to do office work and, when necessary, to keep the entire party in the office for a day to catch up with the office work.

Other Methods.

There are other methods in common use for making topographic surveys. The method which is perhaps most commonly employed for this purpose is that which is sometimes called the railroad method, from the fact that it is generally used in topographic railroad surveys. This method requires the use of base lines, carefully run with transit and chain, with secondary lines at right angles thereto, all elevations being taken with a level. In open country the plane table can be used to advantage to locate the topography, in which case the elevations are taken with a level as when an ordinary transit is used.

For close work in a wooded country, the transit and level is generally preferable. For an open country the stadia method is both rapid and economical and is sufficiently accurate for ordinary work.

Survey of Storage Reservoir.

A survey to determine the capacity of a valley or basin for water storage is usually a topographic survey, which can be made according to one of the methods that have been described; care should be taken to use such methods as are best suited to local conditions.

In practice there are two general methods suitable for determining the cubical capacity of a storage reservoir; these for convenience, may be respectively designated as follows:

1, Method by Contours; 2, Method by Cross-Sections. Each method is adapted to its own special purpose; such method should

be used as will best suit the case in hand. These two methods will be described in order.

METHOD BY CONTOURS.

This method is usually employed when close results are required, in which case a complete topographic survey is necessary. The methods used in making such a survey will usually be decided by local conditions and by the facilities at hand. A complete topographic survey can be made with transit and chain, or with transit and stadia, or with plane table, as has been explained. If the area to be surveyed is covered with brush and undergrowth, or is thickly wooded, the most satisfactory method of making the topographic survey will usually be with transit and chain. In such a case base lines are run with the transit and are marked with stakes at suitable intervals. These base lines may be parallel and at fixed distances apart; or they may be so run that the principal base line will occupy some favorable feature of the topography, such as the top of a ridge, the bottom of a valley, a railroad, or a highway, etc., with other base lines parallel or slightly inclined thereto. Secondary or spur lines are run at right angles, or nearly so, to the bases, so spaced as to fully cover the ground to be surveyed. All lines should be staked at intervals of 25, 50, or 100 feet, as may be required by the conditions under which the survey is made. Levels should be run over these lines, the elevations being noted at each stake and at all intermediate points where changes in slope occur. Contours can be taken with a hand level, using the elevation of the nearest station of the base or spur line as a datum. Topography may be taken according to the methods best suited to the case.

If the country is fairly open, affording opportunity for long shots, the best and most expeditious method of making a survey of this nature will be with transit and stadia. This method has already been explained.

In many cases a plane table can be used with satisfactory results in making a survey of this kind. Any one of the methods that have been mentioned may be best suited to a particular case, under the existing local conditions. Since in most text books on surveying the details of topographic surveying are fully explained it is considered unnecessary to go into such details here. Only such features of the work as are especially concerned with hydrographic surveying will be discussed at length.

Location of Dam. In making a survey for a storage reservoir or basin one of the most important details is the selection of a suitable site for the dam. Since a dam is necessary for impounding the

water it is important that the most advantageous location for building and maintaining the dam should be selected. Considerations affecting the volume of water to be impounded, the cost of the dam, its safety, maintenance, etc., will decide the choice of location. In many instances there is usually one site that is preeminently adapted above all others for a dam and in such a case the survey is made with respect to a dam to be built at this site. In some cases, however, one or more sites offer apparently equal advantages as locations for a dam and in such cases a thorough examination should be made to determine the best site.

It will not be attempted in this manual to discuss the various factors affecting the choice of a dam site since such considerations are within the province of the engineer rather than that of the hydrographic surveyor. The function of the surveyor, for whom this manual is written, is to conduct in the best manner such hydrographic surveys as are intrusted to him; and the scope of this manual will be confined to such work.

Flow Line. The site for the dam having been selected, the elevation of the overflow or spillway is fixed; this determines the height of the water surface. The elevation of the overflow is often decided by the safe height to which the dam may be built. Some times it is fixed by the permissible height to which water may be allowed to rise in the basin; or by the elevation of the surrounding high ground; or by other factors depending upon local conditions. In some cases the elevation of the surrounding high ground above the dam site is the deciding factor in fixing the elevation of the spillway.

The survey having been made, a topographical map is drawn, upon which the position of the flow line is platted accurately to scale; as are also the positions of the several contour lines, whose vertical distances apart are determined by the height of the contour interval.

The outline of the proposed dam is also platted, showing the crest and the toe of slope on either side. The resulting figure will resemble that shown at *a,* Figure 3, in which the flow line and the successive contours are shown by the irregular full lines and the outline of the dam is designated by the full line across them. The intersection of each contour line with the face of the dam will form a straight line from side to side of the valley as shown.

Calculating the Area. The next step is to carefully calculate, separately, the area enclosed by the flow line and by each contour line. The most convenient and expeditious method of calculating

platted areas, with irregular boundaries, is by means of the planimeter. By carefully using this instrument upon an area drawn accurately to scale, very close and accurate results can be obtained. A planimeter is not always available, however, and, where such is the case, areas can be quickly computed by platting them to scale on

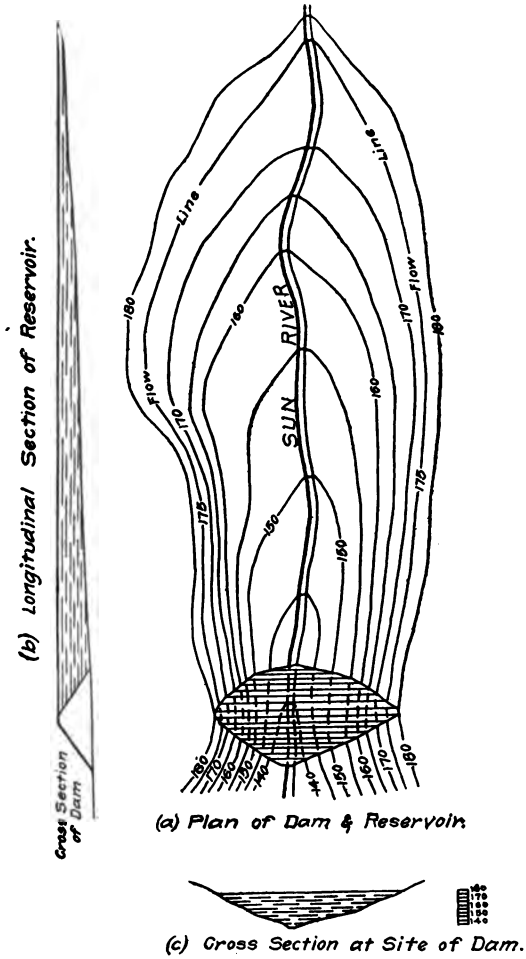

Fig. 3. Contour Map and Section of Storage Reservoir.

cross-section paper, as shown in Figure 4. The area included within each contour line is then determined by counting the small squares and fractions of squares enclosed therein; the aggregate will be the total area of the surface considered. This is a practical and satisfactory method of determining areas of irregular figures where mathematical exactness is not required. Cross-section paper is

cheap and easily obtainable, and irregular figures can be rapidly platted thereon.

Another method of determining such areas is to plat them carefully to as large a scale as possible on drawing paper; then divide the figure into triangles by means of lines drawn between selected points on the boundary. The area of each triangle is computed separately and the sum of the partial areas added together for the entire area. Where the boundary is very irregular, that portion of the figure between the boundary line and the adjacent straight line forming the side of a triangle, can be closely approximated by dividing the included area into small figures, approximating trapezoids or triangles in form, and carefully computing these partial areas.

Calculating the Capacity. The areas enclosed by the several contours having been computed, the reservoir may be considered as consisting of a series of prismoids, whose bases are the areas enclosed by the flow line and by the successive contour lines, and whose altitudes are the contour intervals. A longitudinal section from the upper end of the reservoir to the dam is shown at *b*, Figure 3. A cross-section of the valley at the dam site is shown at *c* in the same figure.

The capacity of the reservoir can be calculated either by the method or average end areas or by the prismodial formula. The first method will give only approximate values and should not be used when close results are required. The second method is far more accurate and should be used where a close approximation is required.

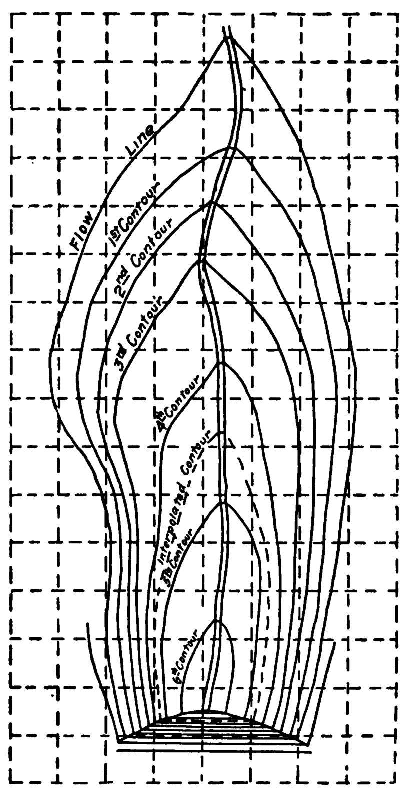

Fig. 4. Contours Drawn on Cross-Section Paper

Example. An example will be given, showing the results obtained by each method, using the same data in each case. The capacity of the reservoir illustrated in

Figure 4 will be calculated, first by the method of average end areas, and then by the prismoidal formula.

	Square feet
Let A_0 = the area enclosed by the flow line..........	1,633
Let A_1 = the area enclosed by first contour	1,229
Let A_2 = the area enclosed by second contour	900
Let A_3 = the area enclosed by third contour	710
Let A_4 = the area enclosed by fourth contour	434
Let A_5 = the area enclosed by fifth contour	187
Let A_6 = the area enclosed by sixth contour	36

The contour interval is five feet.

Then, by the method of average end areas:

$$v_1 = \frac{h(A_0+A_1)}{2};\quad v_2 = \frac{h(A_1+A_2)}{2};\quad v_3 = \frac{h(A_2+A_3)}{2};\quad v_4 = \frac{h(A_3+A_4)}{2};\ \text{etc.}$$

$$v = v_1+v_2+v_3+v_4 \text{ etc.} = h\left(\frac{A_0}{2} = +A_1+A_2+A_3 \ldots\ldots + \frac{An}{2}\right) \qquad (1)$$

In this formula, v_1, v_2, v_3, v_4, etc., are the volumes of the figures enclosed by the flow line and by the successive contours, and **v** is the volume of the entire reservoir. Substituting the given values in the above formula and reducing, we have, discarding fractions,
v_1 = 7155 cub. ft. v_2 = 5323 cub. ft. v_3 = 4025 cub. ft. v_4 = 2860 cub. ft. v_5 = 1553 cub. ft. v_6 = 558 cub. ft. Therefore v = 21,474 cub. ft.

When the prismoidal formula is used two adjacent prismoids are considered as one and every alternate area is used as a middle area. In such a case the height of each prismoid is twice the contour interval. By the prismoidal formula, representing the respective areas by A_0, A_1, A_2, etc., and the respective partial volumes v_1, v_2, v_3, etc., and the total volume by v, and the altitude of each prismoid by 2h, we have:

$$v_1 = \frac{2h}{6}(A_0+4A_1+A_2);\quad v_2 = \frac{h}{3}(A_2+4A_3+A_4);\quad v_3 = \frac{h}{3}(A_4+4A_5+A_6)$$

$$v = v_1+v_2+v_3 = \frac{h}{3}(A_0+4A_1+2A_2+4A_3+2A_4+4A_5+A_6) \qquad (2)$$

Substituting known values and reducing, we have, discarding fractions:

v = 21,402 cu. ft.

If the reservoir is divided into an odd number of prismoids, included between adjacent contours, it is evident that, when the prismoidal formula is applied, there will be a prismoid for which there will be no known middle area. In such a case this final prismoid can be calculated separately by the method of average end areas; this will usually involve no great error when the prismoid is at the

bottom of the reservoir, since in that case its volume is small compared with the remaining volume. A more exact way, however, is to interpolate a middle area between the two final areas and then to compute the volume of the odd prismoid by the prismoidal formula.

Method of Interpolating Areas. The most practical and expeditious way to interpolate a middle area between two adjacent areas whose outlines are known is by the graphic method, on cross-section paper. In order to do this draw the lines bounding the two adjacent areas accurately to scale, in their relative positions, on cross-section paper; then draw a third line midway between the two adjacent boundary lines. This third line will be the boundary of the middle area sought; this area is computed in the same manner as that described for computing the other areas. This method is illustrated in Figure 5, in which the dotted line M is the boundary of an interpolated area between the next larger and the next smaller areas respectively.

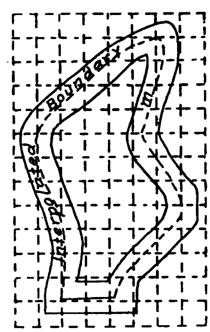

Fig. 5. Method of Interpolating Contour.

In the foregoing calculations no allowance has been made for the space in the channel of the stream which is shown flowing through the valley, since the successive contours have been taken simply to the surface of the water in the stream. When close results are required it will usually be necessary to take account of the stream channel below the water surface, to calculate its volume correctly, and add it to the volume already obtained for the basin.

METHOD BY CROSS-SECTION.

In case it is not necessary to obtain close results in computing volumes the method by cross-sections is by far the cheaper and more expeditious of the two methods for determining the capacity of a storage reservoir. When this method is used the flow line is located on the ground by one of the methods previously described, and cross-sections are taken from side to side of the reservoir at suitable intervals. Generally it is a good plan to first make the outline survey and then to plat it accurately to scale on drawing paper. The plat having been made, the best locations for taking the cross-sections are selected. In the case of an extended survey, around an area of considerable size, selections can frequently be made as the survey progresses and before its final completion. The cross-sections

should preferably be parallel in order to enclose between adjacent sections figures resembling trapezoids as closely as possible. This will result in regular figures and will render the computations simpler than if the cross-sections are not parallel.

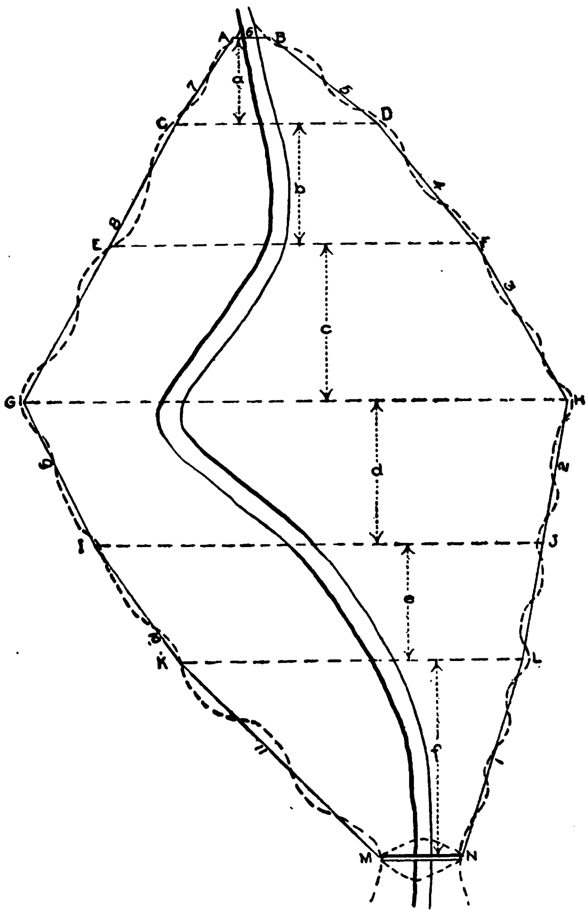

Fig. 6. Outline Map of Storage Reservoir.

If the ground within the flow line has a fairly regular slope the sections should be taken where the best results can be had in determining superficial areas. If, however, the ground is broken and irregular a sufficient number of sections should be taken to afford fairly well proportioned figures. Usually the number of sections taken is governed by the closeness of results required and by the importance of the survey.

The points having been selected, lines are run across the valley, connecting the survey lines on either side. These lines should be staked and the points where their extremities intersect the survey lines carefully noted; also the pluses and angular distances. Levels are then run over the cross-section lines in order to determine the cross-section profiles.

In order to give a practical illustration of this method a plat of a reservoir is shown in Figure 6, in which M-N is the dam site and the lines numbered 1, 2, 3, 4, etc., represent the successive courses of an outline survey, following closely the flow line, which is represented by the irregular dotted line. The parallel sections A-B, C-D, E-F, etc., divide the surface into trapezoids whose bases are the horizontal projections of the respective sections, and whose sides are those portions of the flow line included between adjacent sections. The flow line is usually irregular but may be considered straight between adjacent sections, since when the survey line is closely run it will usually lie about as much within as without the flow line. The superficial area enclosed within the flow line can be determined by computing the area of each trapezoid separately and adding the partial areas together. It is not always necessary to determine the superficial area of a basin or reservoir, but such knowledge is often desirable and can usually be acquired with but little extra labor. In order to determine the capacity of the reservoir it should be treated as a solid figure composed of a series of figures closely resembling prismoids, whose bases are the cross-sections that have been taken, and whose altitudes are the perpendicular distances between adjacent sections. This will be the case when all the sections are parallel, as they should preferably be for convenience in calculation. If the outline of the reservoir is very irregular it may be necessary to take the sections at different angles instead of parallel. In such cases the resulting figures will not usually be prismoids, and their volumes should be calculated by such rules of mensuration as are applicable to them. Each instance of this kind should be treated as a special case; the example given here is applicable to parallel sections. The capacity of the reservoir will be found by aggregating the volumes of the several prismoids and of the two end figures which usually resemble wedges in form. The volumes can be calculated by the method of average end areas or by the prismoidal formula, as previously explained. An example, showing the application of these two methods, will be given in the description of the method for calculating the contents of a lake; this will apply to a reservoir, since the two figures are similar in general shape.

This method of determining the capacity of a reservoir is simple and involves much less labor and expense than a complete topographic survey. The results obtained are not so accurate as those obtained from a topographic survey, but they are usually sufficiently close for ordinary purposes.

Survey of Submerged Area.

One of the most common duties of the hydrographic surveyor is that involving the survey of a submerged area or the survey of territory that is partially or entirely covered by water. A hydrographic survey to determine the sub-aqueous topography of a body of water may be made for one or more of the following purposes:

1. To show the exact conformation of the bottom and as much of the adjacent slopes as may be required; also the variation in level in the water surface, and the character of the material composing the bottom, when required.

2. To determine what changes may be made in the configuration of the channel or basin under consideration; to indicate where material should be removed by dredging or blasting or other means; where material may be dumped for filling or for disposal; and to measure the quantity of material removed or deposited.

3. To indicate what changes have taken place in the bed or channel of a river, canal, or other waterway, either by the filling up of the channel by deposits of silt or mud, or by the erosion of the banks by the action of the weather or the current.

4. To obtain sufficient data for making a map or chart for navigation purposes, or for projecting improvements, such as sea walls, breakwaters, docks, wharves; or for works for bank protection, such as levees, revetments, mattresses, dikes, etc.

A survey of this nature usually involves two distinct operations. It is first necessary to determine the shore line and to locate the position of such of the adjacent topography as may be essential for making a complete map or for fixing the positions of the subaqueous measurements. This is done by outline or topographic survey as previously described, using such methods as are best suited to the case and the local conditions. In many instances it will be necessary to locate by triangulation or by direct measurement a number of prominent objects on shore, such as lighthouses, churches, windmills, etc. Such objects may often be at a considerable distance from the water, and in such cases they are selected for use in locating soundings or other measurements on the water.

The shore line and the necessary topography having been located, the next step in a survey of this kind, will be to measure the depths below the water surface of a sufficient number of points to show the configuration of the bottom. This operation is analogous to the taking of levels in a topographic survey; it differs essentially in detail, however, since in a topographic survey the points where levels are taken are previously located, while the measurements below the water surface must be located at the time they are made. The process of making such measurements is called Making Soundings; it will be described in detail.

CHAPTER II.

Making Soundings—The Sounding Party—Shore Assistants — Equipment — Sounding Machines — The Sextant—Sounding Ranges—Range Signals—Buoys—Locating Soundings—Cooper's Method—Bacon's Method—Reduction of Soundings.

Soundings are usually made either with a pole or with a lead line, according to the depth of the water. For depths of about 18 feet or less a sounding pole can be used to advantage; for greater depths it is customary to use a weighted line, commonly called a lead line.

Soundings are usually made from a boat and sounding operations generally require a party familiar with the work to be done, and an equipment suitable for the work in hand. The size of the party and the kind of equipment required in making soundings will vary according to the nature of the locality where the soundings are made, the extent of the area to be sounded, the method used for locating the soundings, and local conditions of tide, current, etc.

Sounding Party. When soundings are made it is usually necessary to locate them in order that their positions may be platted on a map or chart. A complete sounding party will therefore include, in addition to those required for making and recording the soundings, the observers who locate the soundings, and such assistants as may be necessary, according to the method of location used. For convenience the various members of the sounding party may be classified as follows: *a* observers, or instrument men; *b* sounding crew; *c* boat crew; *d* assistants on shore.

Observers. The observers who locate the positions of the soundings, are stationed at selected points on shore except when the locations are made from the boat, in which case the observers are stationed in the sounding boat. One or more observers may be required, depending upon the method of location. The duties of the observers will be explained in detail under the head of "Locating Soundings."

Sounding Crew. The sounding crew usually consists of a recorder, a leadsman and a signalman. In some cases the recorder

acts as a signalman, and in special cases, where great rapidity is required in the work, two leadsmen are used, who make soundings alternately.

Recorder. The recorder is provided with a note book, in which he records the depths as they are ascertained and called out by the leadsman. He also observes and notes the exact time when each observed sounding is made and performs such other duties as may be assigned to him. These duties will be explained in detail in describing the various methods of locating soundings.

Leadsman. The leadsman is usually an important member of the sounding crew, since upon his skill and rapidity the progress of the sounding party is largely dependent. In shallow water, where a sounding pole is used, for determining depths, the leadsman stands upon a platform in the forward part of the boat, a little back of the bow, and near one side. In making a sounding he plunges the pole into the water, holding it in such a manner that it will become vertical when the foot of the pole reaches the bottom. If the boat is in motion, as will usually be the case, the foot of the pole is thrust ahead at a sufficient angle to reach the bottom, at the same time the boat progresses far enough for the pole to become vertical in the hands of the leadsman. At the proper time the leadsman notes the depth of the water on the pole and calls it out in feet and tenths to the recorder; he then draws up the pole and prepares for the next sounding. In withdrawing the pole from the water the leadsman pulls it up until the foot is within a short distance of the surface, then he "breaks it down" over the side of the bow in front of him, letting it rest there until the next sounding. A good leadsman will, after a little practice, become quite expert in withdrawing the sounding pole from the water in the manner described, as well as in casting it forward to conform to the motion of the boat.

When a lead line is used the leadsman should, for each sounding, endeavor to have the line truly vertical and without sag when the lead touches the bottom and the depth is read. If the sounding boat is in motion he should cast the lead ahead, allowing the line to run out freely until just before the bottom is reached, when the line is pulled taut, causing it to assume a vertical position as the lead touches the bottom. When sounding in a stream or in water where there is a current, the leadsman should be careful not to allow his line to sag or belly under the action of the current before noting the depth. A little practice will enable a skillful leadsman to determine the exact time at which the lead touches the bottom and the

line becomes truly vertical, at which time the reading should be taken. The leadsman should be thoroughly familiar with the markings on the lead line, denoting depths, and in reading the depth of a sounding he should be able to quickly estimate, on a line, graduated to feet, the nearest tenth or half-foot, as may be required. He observes the tag next above the water, in order to determine the correct depth. He should call out, in a clear distinct voice, the observed depth of each sounding to the recorder, who repeats the call to avoid mistake, before entering it in his note book. At suitable intervals, when required, the leadsman notes the character of the bottom, as shown by the material adhering to the bottom of the lead, and calls it out to the recorder. In withdrawing the lead from the water after a sounding the leadsman should lay the line neatly in a coil on the platform upon which he stands, being careful to have successive coils come in their proper places, one above the other, in order that the line will not foul or become tangled as it is paid out for the next sounding. With a little practice the leadsman will usually learn to gage his speed so as to make each sounding at the correct time. This is important when rapid work is required. He should carefully note the condition of his line, the appearance of the tags marking the graduations, and the security of the fastening of the line to the lead. He should at all times be careful to maintain his equipment in serviceable condition.

Signalman. In sounding operations, when the soundings are located by observers stationed on shore, it is customary to have a signalman to notify the observers when to make observations. The signalman is usually provided with a small flag, which he holds in his hand, raising and lowering it, as directed by the recorder, to make the signals. In some cases two flags, one red and the other white, are used, generally the white flag is used for ordinary soundings, and the red flag denotes every fifth or every tenth sounding, thus serving as a check upon the numbering of the observed soundings. Sometimes other forms of signals than flags are used; in either case the signalman should see that the signals are properly displayed.

Boat Crew. The composition and size of the crew for the sounding boat will depend mainly upon the kind of boat used; also upon local conditions of wind, current and tide. If a row boat is used a crew of from two to six oarsmen will be required, in addition to a steersman. In smooth water, where there is little or no current,

two oarsmen will usually be sufficient. In a strong current from four to six oarsmen will be needed, the latter number if the boat is large and if a wind is blowing. The author, in sounding operations on the Mississippi River, where an ordinary row boat was used, found that four oarsmen formed a crew of sufficient size for ordinary service.

Steersman. In sounding upon a range, or where it is necessary to keep the boat on a straight course, a steersman is necessary. In some instances, when few soundings are to be made, or where rapid work is not required, the recorder or the signalman acts as steersman. This arrangement is not practicable, however, when rapid progress is required.

The duty of a steersman is to keep the sounding boat as closely as possible on the range or course upon which the soundings are made. When traversing a range he sights from the front to the back range signal, keeping both signals at all times as nearly as possible in line as the boat moves. When there is a strong current, as in the case of a river, and when the ranges are across the stream, as is frequently the case, it is practically impossible to maintain the boat directly along the range. In such cases a good plan is to start the boat upstream and allow it to drift across the range, making the sounding just as the range is reached. In cases where the current is not too strong, and where the range extends across it, the boat may be kept on range by holding its bow quartering upstream as it moves along.

Power Launch. If a steam or power launch is used for a sounding boat a much smaller crew will be required than for a row boat. In such a case a full sized crew will consist of an engineman, a stoker and a steersman. In some instances only an engineman and a stoker are used for running a power launch; the stoker then acts as steersman when required.

Shore Assistants. In sounding operations, where ranges and range signals are used, it is usually necessary to have one or more assistants on shore to attend to the signals. In cases where movable signals are used, the shore assistants, after sounding work has been finished on a given range, take up the signals from that range and move them over to place on the next range to be sounded. The shore assistants, in addition to placing the range poles or signals, arrange the proper targets thereon to designate the different ranges, and attend to such other details as may be required.

Tide Gage Reader. In tidal waters, where a tide gage is used, it is usually necessary to have a tide gage reader as a member of the shore party. The duties of a tide gage reader consist in observing and noting at required intervals the reading of the tide gage and the force and direction of the wind; this information is recorded by him in a note book provided for the purpose. By referring to this note book the stage of the water at any time during the sounding work can be determined.

Equipment. The regular equipment required for making soundings consists of sounding apparatus and sounding boat. The apparatus ordinarily used consists of either a sounding pole or a lead line, according to the depth of the water to be sounded.

Sounding Pole. A sounding pole should be of suitable length for the purpose required, usually from 12 to 18 feet; it should be sufficiently thick to afford the requisite strength, but not too large around for convenience in handling. Such a pole is usually made round in cross-section gradually increasing in size from top to bottom; with two plane faces diametrically opposite each other, upon which the graduations are marked. For convenience of observation both faces are usually graduated, the graduations being in feet and tenths. The pole should be made of tough, durable wood, preferably ash or hickory; the lower portion should be snugly fitted into an iron shoe or socket which is provided with a flat, disk-shaped base. This base should be large enough to prevent the pole sinking in soft material when resting upon the bottom; it can be provided with a cup-shaped cavity or hollow for bringing up samples of the bottom. When such samples are desired the cavity is coated with

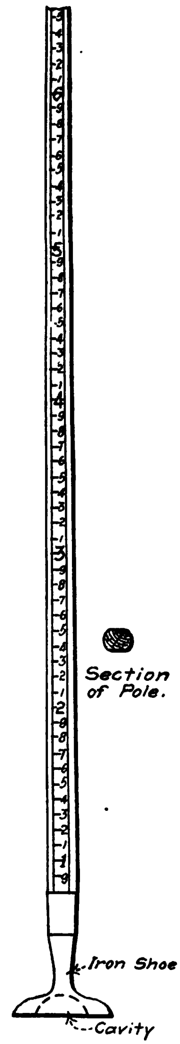

Fig.7. Sounding Pole.

tallow or with a preparation of yellow soap and beeswax, to which the particles of sand or mud adhere.

A good form of sounding pole is illustrated in Figure 7, which shows the shape of cross-section and the graduations; the zero of the graduation is at the bottom of the iron shoe. The rod should be painted white, with the figures designating tenths in black and those denoting feet in red, as in the case of a level rod.

Lead Line. A lead line for sounding work consists of two parts, viz., the lead or weight and the line. The lead is made of some dense, heavy material, usually lead, hence the name; it should preferably be slender in form so as to offer slight resistance in passing through the water. Sounding leads are made in various patterns, that shown at *a* in Figure 8 being a common form. This form is

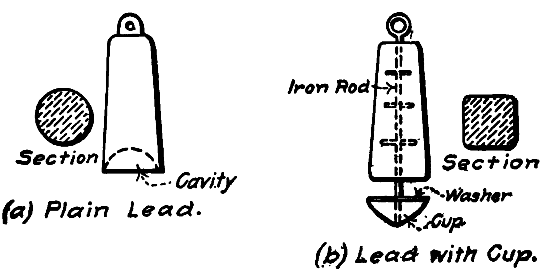

Fig. 8. Sounding Leads.

made of a single piece of lead, slightly conical in shape; the upper part is narrow and flat, with a hole in it through which to fasten the line. At *b* is shown another, and more elaborate form of lead, which is sometimes used when especial care is required in obtaining samples of the bottom. An iron rod, *I*, has moulded around it the lead which gives the requisite weight. At the lower end is attached the cup *c*, which is covered with a leather washer *w*, that slides freely on the iron rod. The cup sinks in the material of the bottom and fills; when it is being drawn to the surface the pressure of the water holds the washer down on the cup and prevents the contents from escaping. When not needed the cup can be removed, in which case the lead is used as an ordinary sounding lead. The weight of a sounding lead for ordinary sounding work varies from 5 to 20

pounds, according to the depth of water in which the soundings are made. For ordinary work, in which the depth does not exceed about 40 feet, the weight of the lead should not exceed 10 pounds, except when there is a strong current. For greater depths heavier leads are required, ranging from 15 to 20 pounds in weight.

The line should be made of strong, durable material, preferably hemp, although other materials, such as linen and cotton, are used. The best lines are made of Italian hemp, closely twisted, and about ⅜ of an inch in diameter. In some cases a wire or a small chain may be used for a lead line. Before being used a lead line, except when it is of metal, should be carefully stretched in order to prevent, as far as possible, changes of length when in use. A good way to stretch a line is to wrap it tightly around a post or tree, or stretch it tightly between two trees or posts and fasten both ends; then wet the line thoroughly and allow it to dry; this causes it to stretch, and there will be considerable slack in it after drying. Then unwrap the line, wind tightly again, and wet it and allow it to dry as before. Repeat this process until the line is thoroughly stretched. Care should be taken not to stretch the line too much, since in that case it will shorten in use.

After being properly stretched the lead line should be graduated to feet, the zero of the graduation being the bottom of the lead. The graduations are marked by bits of white cloth or of leather inserted between the strands of the line, exactly one foot apart. Every fifth marking should be made conspicuous by using a piece of red cloth or a good-sized leather tag. The length of the lead line, from the end of the lead to each 10-foot mark, should be tested before and after each day's use, and the results should be entered in the sounding book. Proper allowance should be made for any errors in the length of the line when the sounding notes are corrected in the office after the field work is done. If, on account of changes in the length of the line, the errors should become large, the tags should be removed and replaced in correct positions, but the markings need not be shifted for small errors.

The lead line should be properly cared for at all times. Some authorities state that it should be kept under water when not in use. The experience of the author shows that good results are obtained by keeping the lead line dry when not in use, and soaking it in water for an hour or two before using. A spare lead line, with lead, should always be kept on hand during sounding work for use in case of accident or emergency.

Sounding Boat. An important part of the equipment of a sounding party is a boat, since boats are required in most sounding operations. For ordinary work, where the area to be covered is not large, an ordinary row boat, preferably of the cutter pattern, will be adequate. Such a boat should be as light as possible, consistent with safety, to permit of being quickly maneuvered; also to allow being beached as quickly as possible, if necessary, by the sounding party in in case of rough weather. It should have, near the bow on either side, a platform upon which the leadsman can stand when sounding; also sufficient seating capacity for the requisite number of oarsmen and other members of the boat party. Lockers or compartments should be provided in the bow and the stern where spare lead lines, oar locks, etc., can be kept, and where sextants or other instruments can be placed for protection from rain, or for other purposes. In Figure 9 is shown in plan a sketch of a row boat suitable for sounding work.

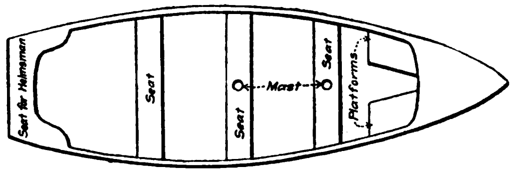

Fig. 9. Plan of Sounding Boat.

Where a large area is to be sounded, or where local conditions will permit, it is usually advisable to use a small steam or gasoline launch for sounding work. Such a boat is much more convenient for this purpose than a row boat. It can be handled with a smaller crew, is capable of greater speed, and can be more rapidly maneuvered than a row boat. In modern practice the power launch has to a large extent superseded the row boat for use in sounding work.

Sounding Machines.

Although the use of machines in sounding work is not common, there are frequently occasions when such devices may be advantageously used. Such apparatus is not part of the regular equipment of a sounding party; since, however, machines are sometimes used for sounding, a description of some of the more modern machines will be given here, also an account of the methods employed in using them.

Various forms of machines have been used in sounding work; most of these were designed for the special conditions under which they were to be used.

A simple form of sounding machine consists of a drum or windlass of good size, mounted upon a suitable frame or support, and

revolving on a horizontal axis. The sounding line is wound around the drum, and is paid out or wound up according as the lead is lowered or raised. On the rim of the drum is a registering device which indicates the depth of the lead at any point. It is so arranged that the registration is zero when the bottom of the lead is at the surface of the water. The principle upon which the registration is based is that each revolution of the drum winds or unwinds a certain length of the sounding line; this length, of course, corresponds to the circumference of the drum. This form of machine is especially adapted for use in sounding through ice. In such cases the machines are mounted upon wheels or rollers, in order that they can be readily moved from point to point as the sounding work progresses.

A form of sounding machine, similar in principle to that just described, is illustrated and described in *Engineering News,* August 7, 1902, in an article written by Otto Gersbach. The illustration, Figure 10, and the accompanying description of the machine are abstracted from this article. The machine consists principally of a drum, 4 feet in circumference, and 18 inches long, with a smaller drum, 4 inches in diameter and 6 inches long, as shown in Figure 10. These are carried by a 3/8-inch axle, projecting 3 inches beyond the supports at each end. The whole machine is mounted in a gas-pipe frame. Around each projecting end of the axle is wound a piece of light picture wire, which extends around pulleys and across the face of the large drum, and is attached to a sliding carriage, which carries a pointer for showing the readings. This wire is wound in opposite directions around the axle at either end, in such a manner that as the drum revolves to lower the lead, the pointer moves from right to left. As the lead is raised the pointer moves to the right. The sounding line, consisting in this case of a wire, is wound around the extreme left of the larger drum. The main part of this drum is graduated as shown, and from these graduations the recorder takes his readings. Around the smaller drum is wound a 1/4-inch rope for revolving the larger drum, in order to raise and lower the lead.

The graduating was done after the machine had been fitted up. The drum was first divided by four horizontal lines, which were a foot apart. These divisions were subdivided into tenths by lighter lines parallel to the others. The spiral division line, extending around the drum, was first traced by a pencil point, held firmly on the pointer while the drum was made to revolve.

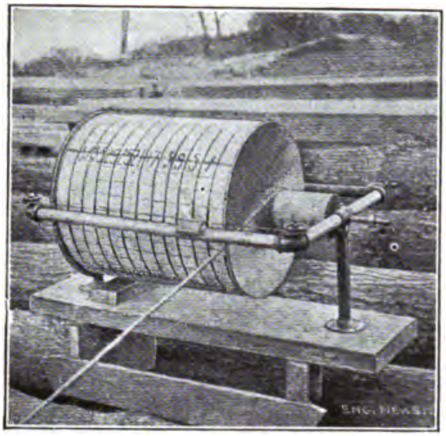

Fig. 10. Sounding Machine.

The machine is placed on a base which rests and is fastened firmly in the back end of the sounding boat, but the cut shows it mounted on a pile of logs for convenience in photographing. In use, one man operates the machine by the rope, which works very easily; a second man does the recording, while a third rows the boat. This machine was designed by Mr. Ben. C. Rich, C. E., for sounding work in Lake Michigan, at Indiana Harbor, Ind. The machine shown in Figure 10 was made by a tinsmith and cost, exclusive of wooden base, $6.85.

Another form of sounding machine is shown in Figure 11. This

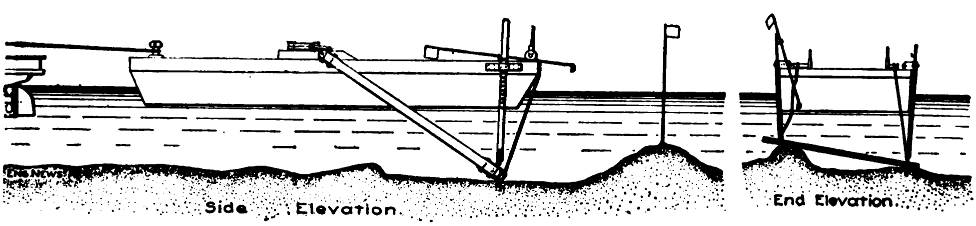

Fig. 11. Sounding Machine.

machine, which was illustrated and described in *Engineering News*, June 18, 1903, was invented by Mr. R. M. Pardessus, of New London, Conn. It consists of a transverse sweep bar attached to the outer ends of two arms, which are pivoted, one on each side of a barge or float, and which extend backward down into the water. The sweep is made of a piece of railroad rail, sufficiently heavy to give the necessary weight for keeping it on the bottom. At the upper end of the pivoted arms is a recording apparatus, which marks the profile of the bottom on a strip of paper moved by clockwork; the vertical motion of the pen is taken by levers from the pivoted sweep arm, which evidently varies in inclination with the position of the sweep. The speed of the barge and the motion

of the paper being adjusted to a known ratio, the curve traced on the paper is a scale profile of the bottom along the range over which the sounding barge moves.

For convenience in reading depths directly, there are two vertical gage rods, one on each side, which are hinged to the ends of the sweep and pass vertically along the side of the barge; these rods are graduated to show the depth sounded. The gage rods are utilized also to throw overboard a marking buoy at every point where the bottom forms a ridge or hillock rising above the proper level; the manner in which this is accomplished is clearly shown in the figure. Whenever either end of the sweep, with the corresponding gage rod, rises as much as a foot or more, a projecting pin on the rod lifts up a marking buoy, previously laid in proper position on deck, and throws it overboard.

This form of sounding machine was designed for use in sounding dredged waters; it has been used by government engineers in examining harbor and channel dredging at New Haven, Conn.

Still another form of sounding machine was described in *Engineering News,* June 16, 1904, from which the illustration in Figure 12 and the accompanying description have been abstracted. It con-

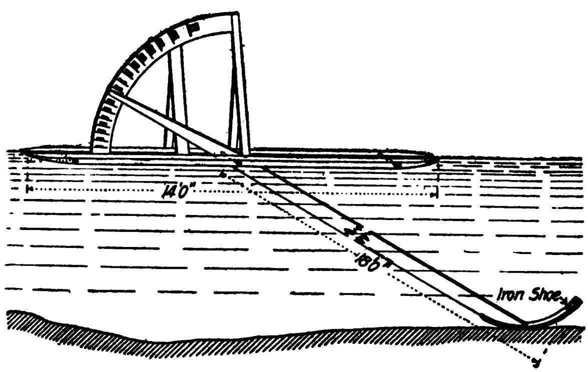

Fig. 12. Sounding Machine.

sists of a raft. supporting a sounding batten, provided with a pivot where it passes through the raft. There is a weight at the lower end of the batten to keep that end submerged. The upper end acts as a finger and indicates on a circular arc the depth of the water on which the apparatus is floating. This sounder is towed alongside a steam launch over the course or range to be sounded. The observer sits at a table in the launch and is provided with a sheet

of cross-section paper, on which the vertical lines refer to positions along the shore, which are indicated by corresponding numbers in a plan lying before the observer. The horizontal rulings refer to depths below the datum used or to heights above it.

As the launch proceeds along a river at a known speed, the observer marks the depths indicated by the sounder at the proper points on the section to correspond with his position along the river; these depths are below the water line at the instant of taking the observations, without reference to the height of water relatively to the datum used. At suitable intervals, say about two miles, water gages are fixed on the river banks, the zero of each gage being referred to the datum; as the launch passes each gage the water level and the time are noted.

When the observer has finished sounding for the day the water level, as read from the gages, is drawn on the ruled diagram form and the sounded depths, as indicated on the section used on the launch, are transferred from depths below the water line at the instant of taking the observations, to depths below corrected water level relatively to the datum. This system of observing and recording soundings admits of very rapid execution. It is, however, adapted for use in comparatively shallow water, say for depths of about 15 feet or less.

Having described the methods used and the equipment required in making soundings, it is next in order to describe the various methods employed in locating soundings. The location of soundings is usually effected by instrumental observation, in connection with base lines and sounding ranges, or suitable objects on shore, whose positions are known. The instruments used in making the observations are respectively, transit, compass, plane table and sextant. Engineers and surveyors in general are more or less familiar with all of the instruments mentioned, with the exception of the sextant; this instrument being generally used for nautical observations, for which it is adapted. Since it is often used in locating soundings it is thought advisable to give a description of this instrument, together with an explanation of its principles and the method of using it.

The Sextant.

The sextant is a hand instrument for measuring angles; it is especially adapted for use in a boat, where the motion of the water renders the use of a fixed instrument impossible. The sextant derives its name from the extent of its graduated arc, which is about the sixth part of a circle.

Description. In Figure 13 is a cut of a sextant showing its construction. It consists of a metal frame C D E, to which is attached the two mirrors B and C, the telescope F, and the index bar C S. The arc D E, which is called the limb, is graduated into 120 or 160 equal parts; each part is equal to half a degree of arc

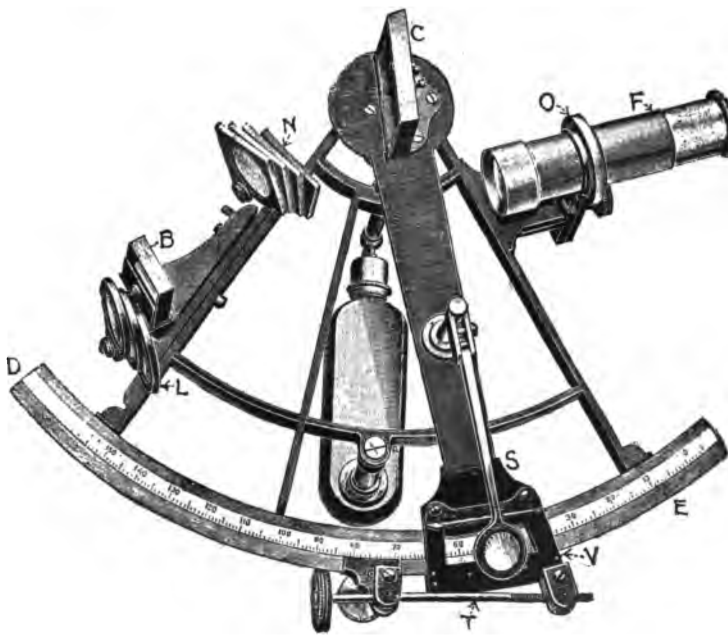

Fig. 13. Sextant.

but is marked as a whole degree, in accordance with a principle that will be explained. The graduations are subdivided into parts corresponding to 10′, 15′ or 20′, according to the size and perfection of the instrument. At C and B are shown two glass mirrors whose planes are perpendicular to the plane of the frame. B is called the *horizon glass;* its lower half is silvered, while the upper half is transparent; it is rigidly attached to the frame of the instrument. C is called the *index glass* or *index mirror.* It is attached to the index bar C S, which is movable on the limb D E around an axis which is centered under the index mirror. The planes of the two mirrors are parallel when the zero mark on the index bar coincides with the zero mark on the limb. F is the telescope which is screwed into the collar O.

The vernier plate V is attached to the index bar, immediately below the graduations on the limb; the index bar is fastened to the limb by means of a clamp screw. T is a tangent screw by which a slight motion can be given to the index bar after it has been clamped. M is a magnifying glass for reading the graduations on the limb and vernier. N and L are colored shades to protect the eye when making observations toward the sun; they can be turned back out of the way when not needed.

Theory of the Sextant. The design of the sextant is based upon the principle that when a ray of light is reflected from a plane surface the angles of incidence and of reflection are equal. The following demonstration of theory is offered: In Figure 14 let S-C

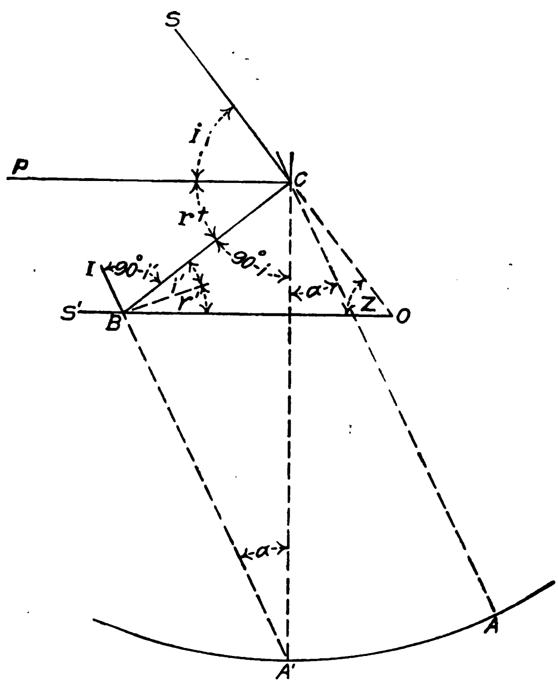

Fig. 14. Illustrating Principle of Sextant.

be the incident ray and C-B the reflected ray; S and S′ are the two objects between which it is required to determine the angle S O S′. The instrument is held in such a position that its plane passes through both objects, while the index bar is clamped at the zero, A, so that the two mirrors are parallel with each other. The index

bar, being pushed forward to A′, so that the reflected image of S coincides with the direct image of S′, seen through the upper or transparent half of the horizon glass, the angle S O S′ measures the angular distance between the two objects; and B A′ C=A′ C A, measures the angle between the planes of the two mirrors.

Since the angles of incidence and of reflection are equal $i = r$ and $i' = r'$. From geometry the exterior angle S C B to the triangle O B C is equal to the sum of the two opposite interior angles C B O and C O B. Similarly, the exterior angle I B C, to the triangle A′ B C, is equal to the sum of the angles B C A′ and B A′ C. This may be stated by the following equations:

$$SCB = CBO + COB \quad (3)$$
$$IBC = BCA' + BA'C \quad (4)$$

But since $SCB = i + r = 2i$; $IBC = 90°\text{-}i'$; $BCA = 90°\text{-}i$; $CBO = i' + r' = 2i'$.

Substituting and calling B A′ C, *a*, and C O B, *z*, we have:

$$2i = 2i' + z \therefore z = 2i - 2i' = 2(i - i') \quad (5)$$
$$(90° - i') = (90° - i) + a \therefore a = (90° - i') - (90° - i) = i = i' \quad (6)$$

Therefore $z = 2a$, or the angle at the eye of the observer is twice the angle between the planes of the mirrors. For this reason the limb is graduated in such a manner that each half degree is marked as a whole degree, and the observer is enabled to read directly from the limb the measured angle between the objects, S and S′.

Adjustments. The adjustment of a sextant should be frequently tested and when necessary, the instrument should be adjusted. The following are the tests and adjustments of the sextant:

1. To make the index glass perpendicular to the plane of the instrument. Place the index bar near the middle of the limb, then look into the index glass and observe if the limb seen direct and its reflected image form a continuous line; if they do the glass is perpendicular to the plane of the limb. If the reflected image appears to be above or below that part of the limb seen direct, the glass needs adjustment. The adjustment is made by means of the small screws at the base of the glass.

2. To make the line of collimation of the telescope parallel to the plane of the instrument. The telescope contains two pairs of parallel wires, enclosing a square space in the field of view; objects to which sights are taken are observed in the center of this space.

Turn the telescope around its axis until one pair of wires is parallel to the plane of the arc. Then set the sextant on a table

or box whose top is horizontal, and sight to some object, as the wall of a room about 20 feet distant; and mark on the wall the place where the line of sight over the horizontal wire strikes. Take two small pieces of wood, each of a length equal to the height of the center of a telescope above the plane of the arc; set the pieces of wood on the arc, as far apart as possible, and sight over their tops toward the point marked on the wall. If the two lines of sight correspond the adjustment is correct; if they do not correspond, adjust the telescope by means of the small adjusting screws in its collar, so as to correct the error. Some instruments are provided with a pair of small peep sights for use in making this test.

Index Error. If a sextant is in perfect adjustment the index reading will be zero when the reflected and direct images of a distant object, as a star, coincide. In many cases, however, it will be found that when two such images are made to coincide, the zero point of the index arm will be either to the right or to the left of the zero point on the limb. The reading of the index is then called the index error. Usually this error is small and is not corrected by adjustment, since such adjustment would disturb any other adjustment of the sextant. The index error is usually applied as a correction to the observed angular readings. If, when the two images are made to coincide, the zero of the index is to the right of the zero of the limb the index error is said to be "off the arc," and is additive. If the zero point of the index is to the left of the zero of the limb the error is "on the arc," and is subtractive from the observed reading.

Use of the Sextant. When used for measuring the angular distance between two objects, the sextant is held in the hand, as previously described, so as to bring the direct and reflected images of the two objects into coincidence, when the angle is read on the limb. The angle is then noted and the index error is applied as in the manner described; the result will be the true angle required. In survey work the sextant is usually held in a horizontal position, or nearly so, and the telescope is directed toward the fainter of the two objects, the more distinct object being observed by reflection. In some cases, in order to accomplish this it will be necessary to hold the sextant upside down, but this will not affect the accuracy of the work.

Sounding Ranges.

When soundings are made over a considerable expanse of water it is necessary that they be made with system and uniformity, and

at suitable distances apart, in order that no time will be lost in making unnecessary soundings, and that soundings will not be repeated over an area that has previously been sounded. For this reason it is customary to make the soundings along lines whose positions are designated by fixed objects on shore, which are visible from the sounding boat during the sounding operations. Such lines are called ranges and the objects designating them are called range signals. Since ranges are often used as factors of location, in fixing the position of individual soundings, it is important that the subject of ranges and range signals be fully understood before taking up the matter of locating soundings.

Range lines should be designated by at least two objects whose distance apart should be great enough to afford a good base for projecting the range over the water to the required distance.

Parallel Ranges. Where the area to be sounded is not large, requiring ranges of only moderate length, the arrangement shown in Figure 15 will often be found suitable. In this case A, B, C, D, etc., represent the front range points or signals, and A′, B′, C′, D′, etc., are the back range signals. The dotted lines 1, 2, 3, 4, etc., are the respective ranges; these, as shown, are parallel and at a uniform distance apart. The lines upon which the front and back range signals are placed are called respectively, the front base line for ranges and the back base line for ranges. The base lines should be laid off with a transit, the distances being measured with a chain or a steel tape. These lines are usually parallel; the locations for the several range signals are marked with stakes or hubs.

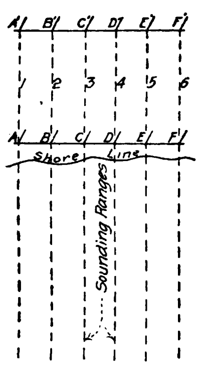

Fig.15. Parallel Sounding Ranges.

Radial Ranges. Where the area to be sounded is large and the ranges are to be projected for a considerable distance, the front and back range signals must be a considerable distance apart, in order to afford a good base for projecting the ranges. In such a case some prominent object of the landscape is usually selected for a back range signal. This should be far enough distant from the front range signals to afford a base of sufficient length for the most distant sounding, and also to permit its use as a common back range signal for all the front range signals, without causing too

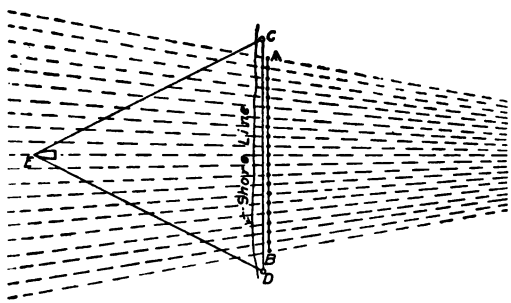

Fig. 16. Radial Sounding Ranges.

great a divergence in the ranges at their outer ends. Such an arrangement is shown in Figure 16. In this case the positions of the front range signals are shown by the dots; they are spaced at known intervals along the base line A-B. The back range signal is a prominent object, as a church spire, at O, not shown in the cut. This is used as a central range point, the ranges represented by the dotted lines, being radial lines passing through the back range point and the several front range points as shown. C-D is a base line at whose extremities, C and D, are instrument stations for locating the soundings. Such a base is usually placed in front of the row of range signals, as shown, in order that an unobstructed view can be had at all times, from either station to the sounding boat.

Ranges Across Streams. In the case of a river or stream, even when of considerable size, where either shore is easily visible from the other side, sounding ranges are generally laid off extending entirely across the stream, in directions normal to its axis. In such a case two sets of range points are laid off; one

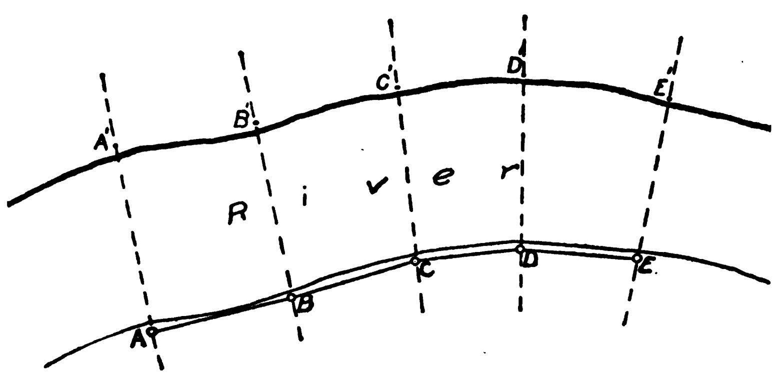

Fig. 17. Sounding Ranges Across a Stream.

set is on either bank as shown in Figure 17. In this figure, A, B, C, D, E are angle points or stations in the line of a traverse

along the river bank, and A-A', B-B', C-C', D-D', E-E' are the sounding ranges. The dots indicate the positions of the range signals; these are placed on either bank as may be most convenient for use in the sounding work.

Range Signals.

Various forms of signals are used for designating sounding ranges; the kind and size of signal required will depend upon the place where used and the distance to which the range is to be projected. For ranges of moderate length, straight poles, of suitable size, may be used for both front and back range signals. In many cases ordinary transit poles, which are painted in alternate red and white bands, make excellent range signals. They can be quickly placed in position at the required places by having their points pressed firmly into the ground; and they can be readily shifted from one range to another as the sounding work progresses. The author has made use of transit rods for range signals with satisfactory results, in sounding operations under his supervision on river work. Ranges so designated were projected to a distance of 1,500 feet and were readily discernible from the sounding boat.

For ranges of considerable length signals of larger size than an ordinary sized transit rod must be used. A good form of range signal can be made of a straight piece of scantling, 4 inches by 4 inches, in dimensions, and from 10 to 14 feet long. Such a signal, when whitewashed, can be seen a long distance. It should be firmly set in the ground in a hole dug for the purpose, or, if set in rocky ground, it should be secured by stones piled around its base; also by bracing or by guy ropes, if required.

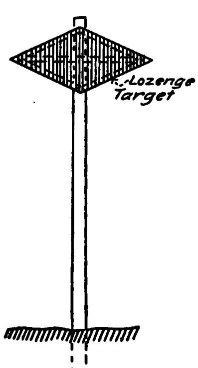

Fig. 18. Range Signal.

Targets. When a number of adjacent ranges are designated by range signals it is necessary to distinguish the different ranges by distinctive marks; such marks are called targets. In Figure 18 is shown a range signal to which is attached a simple but effective form of target. This is made by nailing laths or strips of wood, from 1 to 2 inches wide and about 3 feet long, across the face of the range pole, in such a manner as to form a lozenge shaped frame; a horizontal strip is used to give additional strength. The face of the frame thus formed is covered with cloth

of such a color or combination of colors as may be decided upon. Thus, for example, the target for range 1 may be all white; that for range 2, all red; and that for range 3, red and white, etc.

In a case where the ranges are of such length that the colors on the targets are not readily distinguishable, other forms of targets should be used. A good form of target for use in such cases is made of a framework covered with cloth, and forming an oval-shaped ball, sometimes called a balloon, which fits loosely over the range pole. This form of target, which is illustrated in Figure 19, can readily be raised or lowered as required, and serves to show at once, by its position on the pole, if the range is to be sounded. A modification of this form of target is shown in Figure 20, where a range pole is shown with a balloon at the top and a hexagonal-shaped target below. This latter form of target consists of an open frame with strips of cloth, of suitable color, crossing its face in lattice fashion. It can be raised or lowered by a shore assistant as required. Other forms of targets are used according to available materials that may be had therefor. In some instances targets have been made of branches or limbs of trees, or of small bushes, cut and trimmed to proper size and shape, and attached to the tops of range poles.

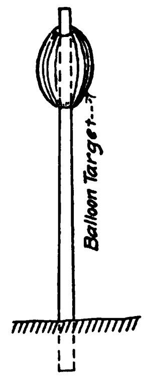

Fig.19. Range Signal.

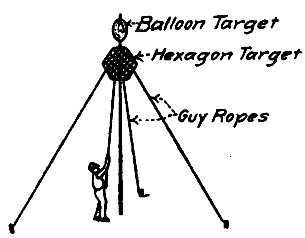

Fig.20. Range Signal.

Range poles used to mark permanent ranges or ranges over which soundings are to be repeated a number of times, are sometimes designated by laths, barrel staves, or strips of wood, which are attached to the face of the pole in the form of Roman numerals, as illustrated in Figure 21.

Such targets, when read from the top downward, denote the number of the range; for example, that shown in Figure 21 designates range number 4. Range poles can be made conspicuous by coating them with whitewash;

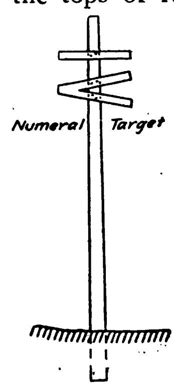

Fig.21. Range Signal.

this is especially effective in the case of a wooded background.

Special Forms of Range Signals. In shallow water, where the depth does not exceed a few feet for long distances from shore, a special form of range signal, suitable for placing in a stationary position in the water, must be used. A good form of range signal that has been successfully used is shown in Figure 22. This consists essentially of a tripod made of three pieces of gas pipe, about 1 inch in diameter, and of suitable length. The lower ends of the pipes are pressed firmly into the soil or mud of the bottom; their tops are then brought together and fastened, forming a tripod as shown. A suitable target is made by wrapping one or two pieces of suitably colored cloth around the tripod, about midway between the water surface and the top of the tripod. Flags are also placed, if required, in the upper ends of the pipes, to further designate the range.

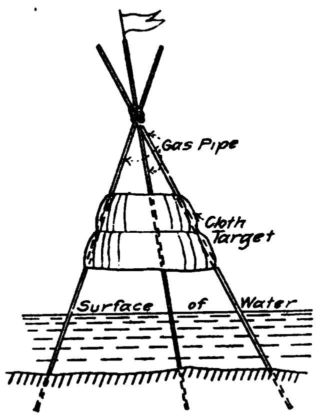

Fig. 22. Tripod Range Signal.

BUOYS.

It is frequently necessary in hydrographic surveying to use range signals in the water where the depth is considerable and where fixed signals can not be used. In the case of a heavily wooded or precipitous shore, where there is not room to set the back range signals very far back, buoys are generally used to designate the front range signals. The use of buoys for front range signals is not always satisfactory, especially in tidal waters, owing to the tendency of a buoy to change its surface position at different stages of the tide. In all cases where stationary signals can be used it is preferable to do so, but in many cases, as above stated, this cannot be done. When buoys are used for range signals due care must be exercised in setting them, and suitable allowance made, in taking observations to them, for change of position due to stage of tide.

A buoy consists of a float, to which is attached a rope or line; this is fastened to a stone or other heavy weight which rests upon the bottom and serves as an anchor. In hydrographic survey work buoys are generally used for range signals, as described above; they are also used to mark the channel, submerged rocks, shoals or other places under water, that require to be shown on the surface.

A simple form of buoy is shown in Figure 23. This consists essentially of two pieces: a float and a pole. The float can be made of a single cylindrical-shaped piece of wood, usually a section of the trunk of a small tree, about one foot in diameter, and about three feet in length. The upper third of the float is usually left full size, the remainder being tapered to from 4 ins. to 6 ins. in diameter at the lower end. Through the center of the float, on its longitudinal axis, a hole is bored, of just sufficient size to admit the pole to be inserted. The pole should be long enough to project from 6 ins. to a foot below the lower end of the float, and from 2 to 3 feet above its upper end. The pole is usually from 1½ to 2 ins. in diameter; after being inserted in the float it should be wedged firmly to place. Near the lower end of the pole a hole is bored horizontally through it from side to side, through which is passed the anchor rope as shown. A flag can be attached to the upper end of the pole to serve as a target. This form of buoy is suitable for use in non-tidal water and in water where the range of the tide is small.

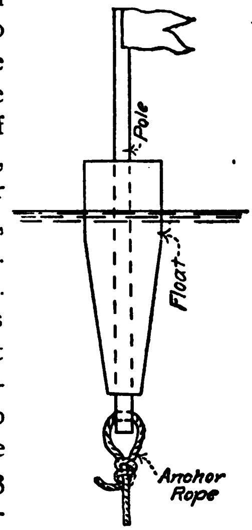

Fig. 23. Buoy for Use in Non-tidal Water.

Another form of buoy is shown in Figure 24. In this form the float is of considerable length and is tapered at both ends as shown. In the upper end a hole is bored for the flag pole, which is driven to place and is held firmly by a wedge in its lower end. A similar pole is inserted in the lower end, as shown, with a hole through it for inserting the anchor rope. If preferred, instead of using a pole, a stout iron ring or hook can be screwed into the lower end of the float for securing the anchor rope. This form of buoy is suitable for use in tidal waters where the range of the tide is not too great. When the range of tide is considerable it is generally preferable to use spar buoys for range signals. A spar buoy is simply a straight piece of wood of approximately cylindrical shape,

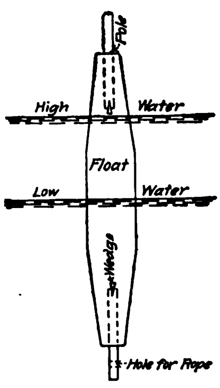

Fig. 24. Buoy for Moderate Range of Tide.

of small diameter and of considerable length; it resembles in shape a spar, hence the name. Many other forms and sizes of buoys than those that have been described are used in hydrographic survey work. The size, shape and material of which made will usually depend upon local conditions and the facilities at hand for the purpose. The forms described are simple, cheap and easily made under ordinary conditions.

Location of Buoys. The location of buoys offshore can be effected by triangulation, as illustrated in Figure 25. The shore stations A and B are located and their distance apart known. Angles are measured at the respective shore stations to the different buoys; in this manner a side and two adjacent angles of a triangle are known for each buoy, from which its location is determined.

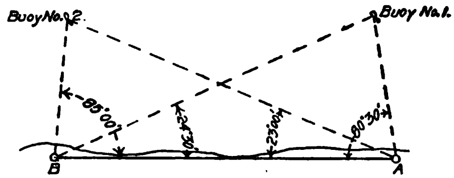

Fig. 25. Location of Buoys.

Locating Soundings.

Before beginning sounding operations, especially when a considerable area is to be sounded, the ranges, stations and points of reference should be carefully located in accordance with the methods that have been described. The order of work should be so arranged that sounding work can be carried on with as little interruption as possible, and as rapidly as possible, consistent with the degree of accuracy required. The position of the sun should be considered so that clear, distinct sights may be had, with minimum inconvenience from glare. If practicable the order of work should be arranged so that the instrument observers will not have the sun in their faces while making observations, but preferably at their backs or overhead. In tidal waters the range of the tide should be considered. If there is a strong tidal current the work should preferably be done in slack water, or when the tide is near half ebb or half flood.

When soundings are located from the shore the observers and assistants on shore should have their watches set exactly with that of the recorder in the sounding boat. Observed soundings are made at stated intervals of time, usually at full minute intervals.

Methods of Location. By the term "locating soundings" is meant determining the relative positions of individual soundings with respect to known points on shore, in order to plat them on a map or chart. Various methods are employed for locating soundings, depending upon the method of making them, the object for which they

are made and local requirements. The following list comprises methods in common use that are adapted to different objects and conditions.

1. Location by time intervals, upon a range of known length and direction.
2. By one angle, measured by an observer on shore.
3. By two angles, measured by two observers simultaneously, on shore.
4. By two angles, measured with sextants, in the sounding boat.
5. By compass bearings, observed in the sounding boat.
6. By transit and stadia.
7. By the intersection of fixed, permanent ranges.
8. By direct measurement on the ice.
9. By a fixed line, marked by a graduated rope or wire.

These several methods will be discussed and described in detail.

Location by Time Intervals. When this method is used for locating soundings the extremities, or two designated points, on a given course or range are fixed by two buoys or other suitable objects, whose relative positions are known with respect to previously located objects on shore. Such an arrangement is shown in Figure 26. In some cases the first and last soundings on the range are

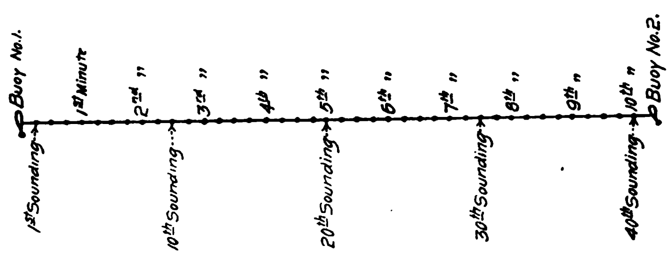

Fig. 26. Soundings Spaced by Time Intervals.

located by measurement or observation, and the positions of the intermediate soundings are interpolated. The sounding boat traverses the range at uniform speed, while the leadsman makes the soundings at known intervals of time, calling out to the recorder the depths of the several soundings. The recorder enters in his note book the observed depth and the number of each sounding, also the exact time each sounding is made. If it is required to know the character of the bottom, this is observed by the leadsman and noted by the recorder as often as may be required. Usually it is not necessary to do this at each sounding, but only at such places where a change in the material of the bottom occurs.

When the soundings are thus made, from a boat moving along a fixed range at a uniform and known rate of speed, the time intervals between successive soundings being known, the position of any given sounding on the range can be determined by proportion. This can be expressed by formula as follows:

Let L be the distance between the extremities or between two designated points on a given range;

T = the time required by the sounding boat to traverse the distance L;

S = speed in units of time of sounding boat

t = the time interval between any two given soundings;

X = the required distance between soundings;

The value of X is determined by means of the proportion:

$$T : L :: t : X \therefore X = \frac{L.t}{T}. \qquad (7)$$

For example, if a sounding boat traverses, at uniform speed, a range 2,640 feet long in ten minutes, and soundings are made from the boat at the rate of four per minute, a total of 40 soundings will be made after passing the initial point on the range. In this case the time interval between successive soundings is one-quarter of a minute and the distance between any two given soundings on the range can be found by proportion as just explained. Thus, referring to Figure 26, let L = 2,640, T = 10, t = ¼.

Substituting these values and reducing, we have:

$$X = \frac{\frac{1}{4}(2640)}{10} = 66 \text{ feet.}$$

This method is employed for locating soundings in cases where great accuracy is not essential and where there is little or no current in the water. It is also used to interpolate the positions of intermediate soundings, between those that are located at stated intervals.

Location by One Angle, Measured on Shore. When this method is used the sounding boat traverses a fixed range, remaining thereon until all the soundings required on that range have been made. The boat then proceeds to the next range where soundings are to be made, the required soundings are made thereon; then to the next range, this operation being repeated until the sounding operations are completed. In this method each sounding range is a factor of location, and it is therefore necessary that all the ranges be accurately located.

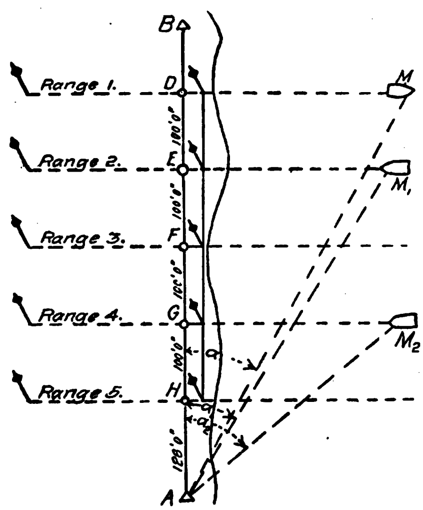

Fig.27. Location by One Angle Measured on Shore.

This method is illustrated in Figure 27, in which A and B represent two instrument stations on shore, whose positions have been determined by triangulation or by direct measurement. The respective ranges are parallel; they are designated by range poles, which are marked with suitable targets. D, E, F, G, H are points of intersection of the base line with the respective ranges; the distances between the extremities of the base line and the respective ranges, as well as the intersecting angles, are known. The positions of the sounding boat at different periods and on different ranges are shown at M, M_1, and M_2.

A regular sounding party for this method of location is composed of an observer on shore, who is equipped with a transit or a plane table, the necessary shore assistants and the boat party. This latter party comprises a recorder, a leadsman, a signalman and the boat crew. Where the same range poles are used for successive ranges, one or more shore assistants will be required to set up and take down the poles and to move them from one range to another. In tidal waters a tide gage reader will be required to observe and record the stage of water at required intervals. The order of sounding work is as follows:

The boat traverses the range, being kept on line by the steersman, who sights to the two signals designating the range and is careful to keep the boat as nearly as possible on the straight line passing through both signals. In some cases the front range pole is shorter than the one in the rear, in order that the back signal may be seen, when necessary, over the top of the one in front. The leadsman stands upon his platform, near the bow of the boat, and makes the soundings at suitable intervals, using a pole or a lead line as may be required, and in the manner previously described. When soundings are observed at one minute intervals, the recorder notes the

time of each sounding and, just before the full minute, he calls out "ready," at which the signalman raises his flag to notify the observer on shore that a sounding requiring observation is about to be made. At the full minute the recorder calls out "flag" or "sound," as he may prefer, when the signalman drops his flag at the same instant that the leadsman makes the sounding. When soundings are made rapidly, it is not usually practicable to observe each sounding, and in such cases it is customary to observe those made at the end of each minute and to interpolate the intermediate soundings by time intervals. As each sounding is made the leadsman calls the observed depth to the recorder, who enters it in his note book, together with the number of the sounding and the exact time.

The observer sets up his instrument, preferably a transit, over a selected point on the base line, sets the vernier at zero, sights along the base line and fastens the lower clamp. He then loosens the upper clamp and turns the instrument in azimuth until the line of sight is directed toward the sounding boat; as soon as the signal flag is raised he sights to it, and by gently turning the telescope in azimuth, keeps the line of sight fixed on the flag until it is lowered. At the instant the flag drops the observer ceases to turn the telescope, observes the time by his watch, which should be lying open, with face up, on the instrument before him; then reads the angle, as *a*, Figure 27, and enters in his note book the angle and the time. Angular measurements are made at suitable points on the base line or at either extremity of the base, care being taken to secure good intersections with the respective sounding ranges.

When this method of locating soundings is used there are two factors of location, the sounding range constituting one factor and the observed angle the other. Thus, referring to Figure 27, in order to locate the sounding made when the boat is at M, the following method is applicable: The direction of range I is known by the angle of intersection between it and the base line at D; the distance A-D and the angle *a* are known. The triangle A D M can then be solved and the distance D-M determined; this locates the sounding on the range numbered I.

Location by two Angles, measured simultaneously on Shore. In using this method two observers are required, who are stationed at suitable points on a base line, and who measure simultaneously the angles between the base line and the two respective lines of sight to the sounding boat at each sounding. If sounding ranges are not used, the factors of location are the base line, upon which the ob-

servers are stationed, and the two angles that are read from its extremities. This is illustrated in Figure 28, in which A-B is the base; A and B are the two observation stations and A-C and B-C are the two lines of sight. An instrument, preferably a transit, is set up at each observation station, with the vernier of each instrument set at zero upon the other transit; each observer has his watch lying open and face up, on the upper plate of his transit. The lower plate of each transit is clamped and the upper plate is free; the movement of the boat is followed by the telescope, moving in azimuth, in the manner previously explained. The sounding boat, being at the position *C* at the time a given sounding is made, the angles *a* and *b* are measured. Then in the triangle A B C, the side A-B and the two adjacent angles, *a* and *b* are known; the triangle can be solved and the point *C* located with respect to A and B.

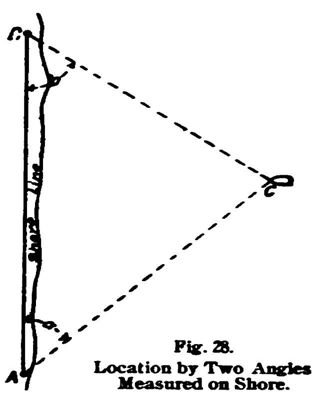

Fig. 28.
Location by Two Angles Measured on Shore.

In practice it is customary to make the soundings upon established ranges, both for convenience in platting and for facility in determining where to make the successive soundings. The ranges may be parallel, as shown in Figure 15, or radial, as shown in Figure 16. In either case the ranges serve as factors of location, as well as to check the accuracy of the angular measurements.

In Figure 16 the sounding boat is shown traversing range II and going from shore. A perspective view of this is shown in Figure 29, in which the sounding boat, a steam launch, is in the fore-

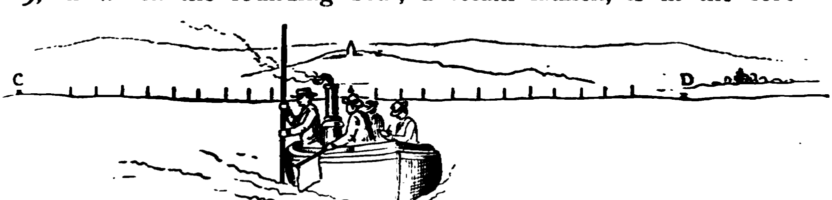

Fig. 29. Sounding Party in Steam Launch.

ground, the back range signal, a church spire, is in the background, and the front range signals are in the middle distance. The sounding party consists of a boatman, who acts as steersman, a recorder, a leadsman and a signalman. The soundings are located by the observers on shore at one minute intervals. A few seconds before

the end of each minute the signalman raises his flag and, at the full minute, the flag is lowered, simultaneously with a sounding made by the leadsman. The observers on shore follow with their lines of sight the signal flag and, as it is lowered, observe the respective angles and the time, and record both in their note books. In this case the distances from the instruments to the sounding boat are considerable and sights are taken to the flag instead of to the sounding pole in the hands of the leadsman, as would be the case for short distances. On this account the signalman is stationed near the leadsman in order that the distance between the observed and the true position of each sounding may be as small as possible.

As the boat moves over each range at uniform speed the soundings are made regularly, three or four to the minute, according to the depth of the water. Those made on the full minute are located by observation, and the intermediate soundings are interpolated by time intervals, as previously described.

After each range is run out the boat starts back on the next range, thus alternately beginning and ending at the shore for successive ranges.

Fig. 30. Sounding Boat.

COOPER'S METHOD.

For very rapid work, where soundings are located by two angles, observed on shore, a method devised by Mr. A. S. Cooper, United States Assistant Engineer, and used by him in hydrographic surveys in the Savannah, Georgia, district, is well adapted. The following description and illustration of this method are taken from an article written by Mr. Cooper and published in *Engineering News,* May 19, 1904.

The sounding boat used was a 40-foot steam launch, a view of which is given in Figure 30. The sound-

ing party, on the boat, consisted of two leadsmen, a recorder, a signalman, an engineman and a steersman. The order of sounding operations, as described by Mr. Cooper, is as follows:

The two leadsmen occupy sounding platforms, one on either side of the boat, as shown; they make soundings alternately, at intervals of 10 seconds in depths of from 20 to 35 feet. In shallower water the soundings are made more rapidly, and for depths greater than 35 feet the rate of speed is less. The boat, as shown, has a signal mast, which is provided with a signal balloon capable of being raised and lowered. The recorder calls "lead" at the end of every 10 seconds, thus notifying a leadsman to sound; at 10 seconds before the full minute, in addition to calling "lead," he calls for the signalman to hoist the balloon; at the full minute, as a sounding is made, the signalman drops the balloon, thus notifying the two observers on shore to note the angles to the signal mast at the instant the signal begins to fall.

Location by two Angles, measured in the Sounding Boat. This method, which is extensively used in harbor surveys, requires the previous location of three prominent objects on shore, which are visible from every portion of the area to be sounded, and which are suitably located for good intersections from the sounding boat As each sounding is made, two angles are measured in the boat to the three fixed shore points. The angles are measured simultaneously by two observers, each using a sextant, or by one observer with a double sextant. When rapid work is not required both angles may be measured successively by one observer with a plain sextant; in such a case the boat is brought to a stop for each sounding. This process, however, is slow, and the method commonly employed is that in which two observers make simultaneous observations.

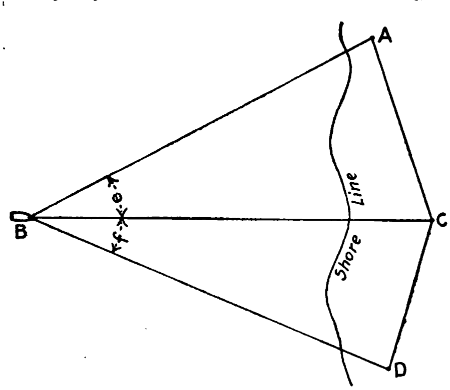

Fig.31. Location by Sextant Angles, Measured in Boat.

A complete sounding party for this method consists of two sextant observers, a leadsman, a recorder and the necessary boat crew. In tidal waters a tide gage observer is required on shore, otherwise the entire party is carried in the sounding boat. In order to clearly describe this method of

location reference is made to Figure 31, in which A, C and D represent the three fixed shore points and B is the position of the sounding boat at the time a given sounding is made. In order to locate the sounding the angles *e* and *f* are measured; the position of the sounding is fixed by the intersection of the three lines of sight, A-B, C-B, and D-B. The problem involved in the location of soundings by this method is called the three point problem; it can be solved algebraically as follows:

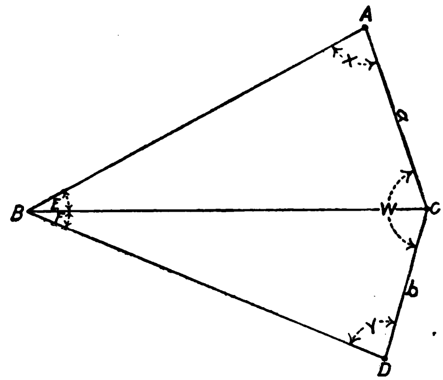

Fig. 32. Sketch Illustrating Three Point Problem.

Let A, C, D, Figure 32, be three fixed points, whose positions are determined by the angle *W* and the sides *a* and *b*. The angles E and F are measured. The problem is to determine A-B and D-B. In order to do this the angles *x* and *y* are first determined, as follows:

In the triangles A B C and C B D, from trigonometry,

$$C - B = \frac{a.\sin X}{\sin E} = \frac{b.\sin Y}{\sin F} \qquad (1)$$

$$x + y + W + E + F = 2 \times 180^\circ = 360^\circ. \qquad (2)$$

and

$$x + y = 360^\circ - (W + E + F) = S \qquad (3)$$

whence

$$y = S - x \qquad (4)$$

and,

$$\sin y = \sin S.\cos x - \cos S.\sin x \qquad (5)$$

substituting this value of sin y in (1),

$$\frac{a.\sin x}{\sin E} = \frac{b\ (\sin S.\cos x - \cos S.\sin x)}{\sin F} \qquad (6)$$

clearing of fractions,

$$(a.\sin F - b.\cos S.\sin E) = b.\sin S.\sin E \qquad (7)$$

Dividing by cos x and transposing, and since $\frac{\sin x}{\cos x} = \tan x$

$$(a.\sin F + b.\cos S.\sin E)\tan x = b.\sin S.\sin E \qquad (8)$$

$$\tan x = \frac{b.\sin S.\sin E}{a.\sin F + b.\cos s.\sin E} \qquad (9)$$

The value of tan y may be determined in the same way; or, having determined x, its value is substituted in equation (4) and the value of y is found direct.

Having found x and y, the values of A-B and D-B are determined by trigonometry as follows: In the triangle A B C the side a and the two angles E and x are known. The angle $ACB=180°-(E+x)$ (10)

$$\sin E : \sin ACB = a : A-B; \text{ whence } A-B = \frac{a. \sin ACB}{\sin E} \qquad (11)$$

similarly, in the triangle D B C, $DCB = 180° - (F + y)$ (12)

$$\text{whence } D-B = \frac{b. \sin DCB}{\sin F} \qquad (13)$$

Example.—Given a=850 feet. b=760 feet. E=41° 30′. F=35° 30′. Referring to Figure 27, what are the values of the angles x and y, and of the sides A-B and D-B?

Solution. Substituting these values in equation (3)

$$x + y = 360° - 227° = 133° = S$$

since S is in the second quadrant, $\cos S = -\cos (180°- S) = -\cos 47°$, substituting in equation (9)

$$\tan x = \frac{760\times0.\ 7315\times0.\ 66262}{(850\times0.58070) - (760\times0.\ 6820\times0.66262)} = \frac{368.3}{150.15} = \underline{2.4529}$$

$$x = 67°49'.\ y = 133°- 67°49' = 65°11'$$

substituting in equations (10) and (12),

$$A\ C\ B = 180° - 109°19' = 70°41'$$
$$D\ C\ B = 180° - 100°41' = 79°19'$$

then substituting in equations (11) and (13),

$$A - B = \frac{850\times0.\ 94370}{0.66262} = 1210.56$$

$$D - B = \frac{760\times0.\ 98267}{0.\ 58070} = 1286.08$$

This method of locating soundings is extensively used in harbor work; it is probably the best known general method.

BACON'S METHOD.

A very rapid method of platting soundings when the locations are made by means of sextant observations from a boat, has been used by Mr. James H. Bacon, United States Assistant Engineer, for hydrographic surveys made off the coast of Florida. A description of this method, written by Mr. Bacon, was published in the report of the Chief of Engineers, United States Army, and also in *Engineering News* of March 26, 1903.

In describing this method it is first necessary to explain the principle upon which it is based. In Figure 33 let A and B represent two known points on shore, and C be the position of the sounding boat at any given sounding. If a circle is drawn through A, B and C, an observation made at any point on the arc A C B, will subtend an angle equal to the angle at C. This is evident from the well known principle of geometry that all the angles inscribed in the same segment of a circle are equal. Thus if the angle B A C = 63° an observation made to A and B at any other point on the same arc, as at C_1 will also measure 63°.

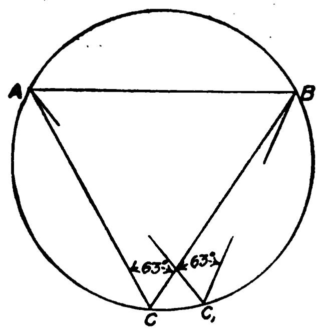

Fig.33. Inscribed Angles.

If a number of arcs, of different radii, are drawn through the same two points, the inscribed angle on each arc will depend upon the length of its radius. In Figure 34 is shown a series of arcs whose centers all lie on a line which is drawn perpendicular to the line A-B, at a point half way between A and B. For convenience these arcs are drawn so that successive inscribed angles will differ by a constant interval. In this case any given angle subscribed by the two points will be on one of the arcs or can be interpolated between two adjacent arcs.

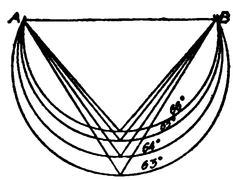

Fig.34. Series of Arcs.

If a second series of arcs is drawn through two other points, suitably located, the intersections of the two series will locate readily the position of any point within the area covered by them. Let A-B and C-D, Figure 35, represent two base lines, through whose extremities are drawn two series of arcs, as shown; the points A, B and C are prominent objects on shore, whose positions are known. The centers of each series are located on a line, perpendicular to the base line and passing through its center; and the arcs are drawn with an interval of 1° between adjacent arcs. A point whose observed angular values are whole

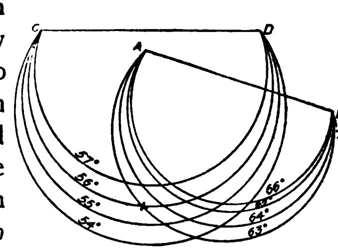

Fig.35. Intersecting Arcs

degrees, will be found at the intersection of the two arcs corresponding with the observed angles. Intermediate points are found at distances interpolated between adjacent arcs.

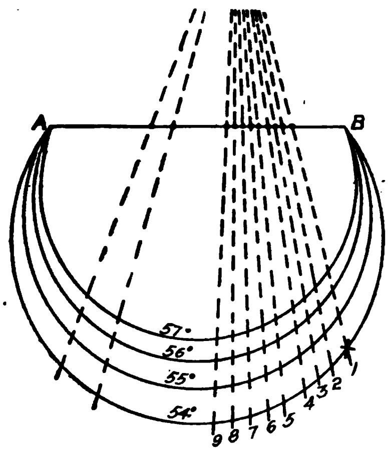

Fig.36. Radial Intersections.

In some cases, when this method is used, the sounding boat is kept on a fixed range while the soundings are located by sextant angles to two known points on shore. When this is done the sounding ranges may be either radial or parallel, the former arrangement being usually preferable. In the case of radial ranges, a prominent object, whose position is known, as O, Figure 36, is selected for a back range point, and a number of ranges, radiating therefrom at regular intervals, are laid off. The back range point, O, should be at a distance from any front range point not less than the distance from the front range point to any sounding to be located on that range; it should be a conspicuous, well defined object, such as a lighthouse, a church spire, a windmill, a water tower, or other prominent available object. In order to afford good locations the back range point, O, should appear, for all observations, between the two extremities of the base, A-B. The front range points are marked by suitable signals, in the manner previously explained.

When parallel ranges are used the arrangement will usually be similar to that shown in Figure 37. In such a case the range points are located and the ranges are laid out according to the manner previously described. The back range points should be located far enough back from those in front to afford good bases for prolonging the sounding ranges.

Methods of Location. In using these methods the soundings are located by sextant observations in the same manner as that previously described for such work.

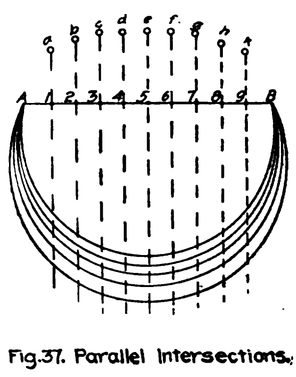

Fig.37. Parallel Intersections.

When two base lines are used, as illustrated in Figure 35, simultaneous obser-

vations are made by two observers, for each sounding; one observer measures the angular distance between A and B, while the other observer measures that between C and D. In locating soundings by range and base line, as illustrated in Figures 36 and 37, the sounding boat is kept on the range by the steersman while the soundings are made. Since only one angular measurement is required for each sounding, the observations can be taken by one sextant observer.

The methods just described are best adapted for hydrographic work when a number of surveys are to be made over the same area, successively, and each survey involves many soundings.

When soundings are located by sextant observations from a boat, practically the entire party is carried in the sounding boat, thus affording unity of action and avoiding loss of time when a change of plans is required. Locations made with transits are perhaps more exact, but sextant observations are usually sufficiently accurate to conform to the scale of the map or chart.

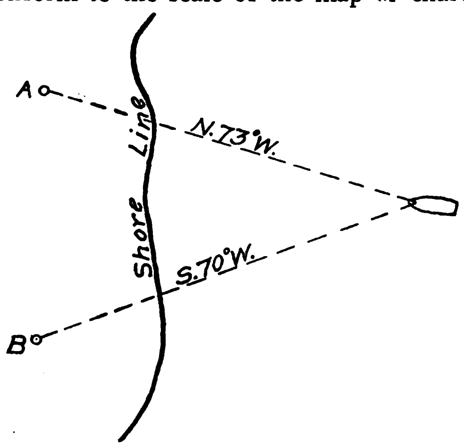

Fig. 38. Location by Compass Bearings.

Location by Compass Bearings. This method of locating soundings is rather crude and should not be used where accurate results are required. In order to use this method it is necessary that two conspicuous objects on shore, that can be readily seen from the sounding boat, as A and B, Figure 38, shall first be located and their positions known. In locating the soundings two observers, each with a compass, are required in the sounding boat, in addition to the boat crew. Each observer selects a different object for observation and, as soon as a sounding is made, the two observers read the magnetic bearings to their respective objects. Thus, referring to Figure 38, for the sounding made at C, one observer notes the bearing C-A, while the other notes the bearing C-B. If rapid work is not required both observations may be made successively, by one observer, in which case the boat must be brought to a stop for each sounding.

Location with Transit and Stadia. In locating soundings by this method the complete party is usually divided as follows: 1. The observer on shore, with a transit equipped with stadia wires. 2. The boat party, consisting of a recorder, a leadsman, a stadiaman, a signalman and the necessary boat crew. Several variations of this method may be used according to local conditions and the degree of accuracy required in the work. When soundings are made on an established range, the transit is set up over some known point on the range, as at A, Figure 39, and observations are taken for soundings on that range. In this case the azimuth of the range is known and the distance of each sounding from the transit station is determined from the observed interval on the stadia rod. As the boat traverses the range the stadiaman stands in the bow or the stern of the boat, according to whether the boat is approaching or going from the observer; he holds his rod vertical and always facing the observer. The leadsman makes the soundings at the required intervals, calling out to the recorder the depths and, when required, the character of the bottom. The recorder enters this information in his notebook, also noting the time and the number of each sounding. The signalman raises and drops his flag to notify the observer when soundings are made, in the manner that has been previously described. The observer notes the number of the sounding, the time and the stadia interval for each observed sounding. The method just described is suitable for locating soundings made on ranges across rivers or sheets of water where the distance from shore to shore is not too great for stadia readings.

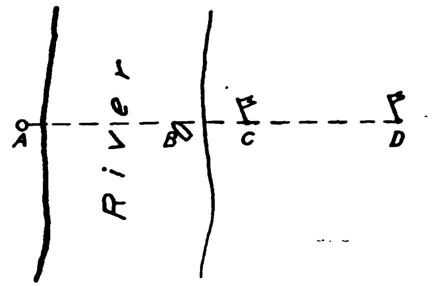

Fig.39. Location by Stadia on Range.

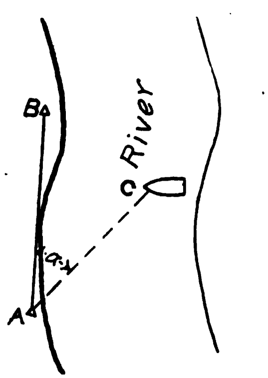

Fig.40. Location by Stadia and Azimuth.

When the soundings are not made on ranges, or when they are made on a range and it is

not convenient to set the transit up over a point on the range, the azimuth for each observed sounding is noted, in addition to the stadia interval therefor. The azimuths can be determined with reference to a true or an assumed meridian, or by measuring the angular distances from a previously established base line, whose azimuth is known. This is illustrated in Fig. 40, in which A-B is the known line, A the position of the transit, and C the position of the sounding boat at the time of a given sounding. The factors of location are the angular distance, a, determined by azimuth reading, and the distance A-C, determined by the stadia interval. When soundings are made on a range it becomes a third factor of location.

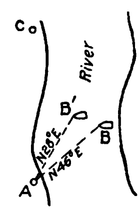

Fig. 41. Location by Stadia and Compass.

Where accuracy is not essential and rapid work is required, the directions to the several soundings can be determined by compass bearings, and the distances by stadia. In such cases it is not necessary to use a base line; it will be sufficient to know the location of the shore point from which the observations are taken. Thus, referring to Figure 41, the transit is set up over the shore point, A, which has been previously located, and readings are taken to the sounding boat as the soundings are made, as, for instance, at B and B′. In this instance the magnetic bearing from A to B is N 46° E, and that from A to B′ is N 28° E. When the area visible from A has been sounded, the transit is moved to another shore station, as at C, and the same process continued. The new shore station can be located by observing the bearing and the stadia interval thereto from the previous station.

Location by the Intersection of Fixed Ranges. In a case where a sounding range is to be sounded many times, and where it is required that soundings shall be made at the same points each successive time, it is generally advisable to provide some arrangement by which selected points may be identified at any time. In many instances it is necessary to determine the cross-section of a river or stream, at a discharge station at successive periods; often a series of observations must be made across a channel to ascertain if the bottom is scouring or is filling up with sediment. In such cases the location of successive soundings may be effected by intersecting ranges.

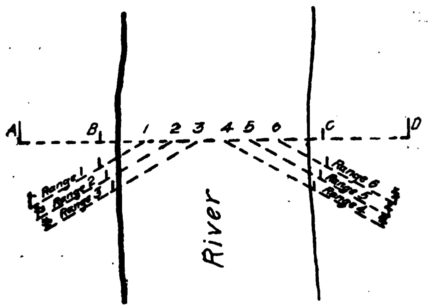

Fig. 42. Location by Intersecting Ranges.

Such ranges can be laid out in several different ways; a good arrangement is that shown in Figure 42, in which A-D is a sounding range across a river, and 1, 2, 3, etc., are the points at which successive soundings are to be made. Range poles designating this range are set at A, B, C and D; those nearest the water are shorter than the back range poles, in order that the latter may be readily seen over the tops of the front range poles. The ranges numbered 1, 2, 3, 4, 5 and 6 are also designated by range poles as shown. If desired, the back range pole in each range is marked with Roman numerals, showing the number of the range. The intersections of the numbered ranges with the range A-D, locate the respective sounding points.

Another arrangement for intersecting ranges is that shown in Figure 43. In this instance all the numbered ranges on a side are referred to a single back range pole; the front range poles may be marked with Roman numerals, denoting numbers of respective ranges.

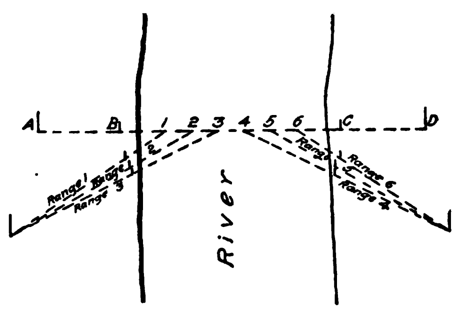

Fig. 43. Location by Intersecting Ranges.

When making soundings in a current, using this method of location, the boat is started at a short distance upstream and is allowed to drift downstream to the range. The leadsman casts the lead in time for the line to become vertical as the proper place is reached. Care should be taken not to cast the lead too soon, since in a strong current, the lead line will have a decided sag if exposed to the force of the current for an appreciable time after the lead touches bottom.

Location by Measurement on Ice. When climate and season are favorable a hydrographic survey may be made upon the frozen sur-

face of a stream or other body of water. In such a case, lines are run and measurements are made on the ice in practically the same manner as on land. Soundings can be located by stadia observations, or by direct measurement, as may be best adapted for the case. At points designated for soundings, holes are cut through the ice and the depths below the surface, to the bottom, are measured with a lead line or pole. Sounding machines, such as previously described, have been successfully used for sounding through ice.

Location by Graduated Wire or Rope. In a case where soundings are to be made across a canal or stream of moderate size, where the span is not so great as to cause much sag, locations can generally be made on a rope or wire, stretched from bank to bank. Where it is necessary to sound the same sections a number of times, the points on each bank, between which the rope is stretched, can be marked with stakes or hubs, firmly driven into the ground, as illustrated in Figure 44. The stakes, A and B, are spaced at a known distance apart, and the line connecting them is preferably normal to the local axis of the stream. Tags or markers are placed at known intervals along the rope so that, when the rope is stretched from stake to stake, distances along it can be readily determined. Soundings can be located at the same points as frequently as necessary by stretching the rope between the same stakes each time sounding work is done.

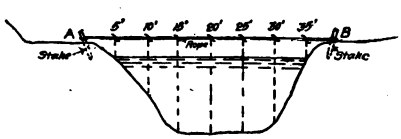

Fig. 44. Location by Graduated Wire or Rope.

This method is well adapted for determining cross-sections of a narrow channel before and after dredging operations. The author has made use of this method in the survey of a navigable canal, whose channel required deepening, both to determine the amount of dredging necessary and to ascertain the quantity of material removed by dredging. In this instance a traverse survey was first made along the canal towpath, with stations 100 feet apart. The stations were designated by stakes driven nearly flush with the surface, and the line was run as close as practicable to the water side of the towpath, in order to avoid the danger of the stakes being disturbed by traffic. Each stake marked one extremity of a sounding range, which extended across the canal, and whose other extremity was marked with a stake on the opposite bank. This arrangement is illustrated in Figure 45, in which it is seen that the ranges are normal to the general axis of the channel. The ranges were designated by a rope which was first thoroughly

stretched and afterward graduated by inserting between the strands, bits of cloth at intervals of 1 foot. The 5-foot marks were made conspicuous by using red cloth for tags; the other graduations were marked with white cloth. When used for designating a range, the rope was held firmly against a station stake, at some convenient foot mark, and was pulled taut across the canal and held against the stake on the opposite bank. For such work two assistants were required, one on either bank; they held the rope in place while soundings were being made, pulling it sufficiently hard to prevent undue sag. The sounding party, in a boat, consisted of a recorder, a leadsman, provided with a sounding pole, and a boatman. In sounding a range, the boatman, holding the rope with his hands, pulled the boat across the canal, on the range, from one side to the other, as the soundings were made. The leadsman, in making a sounding, held his pole vertical and against the rope, noting the depth and also the graduation on the rope that was next to the pole. Depths were noted in tenths and horizontal distances were observed to whole feet; these were both called out by the leadsman to the recorder, who entered them in his notebook. After a range had been sounded, the two assistants on shore proceeded to the next range, carrying the rope between them, and holding it clear of the water. At the next range the rope was stretched from stake to stake as before; the boat in the meantime having been paddled or towed by the boatman to the proper place, the new range was sounded in the same manner as before. These operations were continued for successive ranges until all the sounding work, that was required prior to dredging operations, was finished.

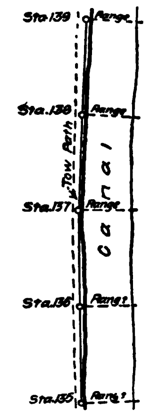

Fig.45. Sounding Ranges Across Canal.

After the channel had been dredged, the ranges were again sounded; the sounding work was done in the same manner as at first. The original sounding places on a range were identified by holding the rope against the same stakes, at the same graduations, as for the original soundings.

The Reduction of Soundings.

The Plane of Reference. After soundings have been made in a given locality, or over a given area, it is necessary to reduce them to a common datum or plane in order to determine correct elevations of the bottom at all points where individual soundings were made.

Since in all bodies of water the water surface is subject to fluctuations in height, it is customary in sounding work to take for a datum some known stage of the water to which all observed depths are referred. Such a datum, which is usually a very low stage of the water, is commonly called a plane of reference.

In tidal waters the elevation of mean low tide is generally taken as the plane of reference, and upon maps or charts showing depths of soundings made in tidal waters, unless otherwise indicated, the depths shown are below the level of mean low tide. When soundings are made in a lake, or a reservoir, or other similar body of water, is is customary to use as the plane of reference the lowest known stage of the water. In rivers or streams or variable stage, the low water stage of the river is used in some instances as the plane of reference; in other instances the bottom elevations, as determined by soundings, are referred to the general datum of the survey. In many cases the plane of reference is taken as the low water contour of the portion of the river sounded, and not the horizontal plane passing through the low-water mark at some selected point.

Water Gages. In order to determine the height of the water at any required time during a hydrographic survey, it is necessary to employ some suitable method to indicate the water level at all times. This is generally done by means of water gages, which should be located at such places as are most suitable and convenient for observation. Water gages for this purpose are of two general kinds, viz.: staff gages and automatic gages.

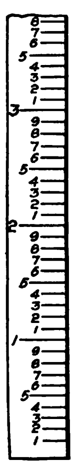

Fig. 46. Staff Gage.

Staff Gages. The type of water gage commonly used in regular sounding work is the staff gage, which resembles in general appearance a self-reading level rod. A common form of staff gage is made of a board or strip of wood, from three to 6 inches wide, and from one-half inch to one inch thick, and of suitable length. It is painted white and is graduated on the face to feet and tenths. The numerals indicating tenths are black, and those designating feet are red. A good form of staff gage is illustrated in Fig. 46; in this form, the 5-tenth marks and the foot marks are made conspicuous in order to facilitate reading.

A staff gage for use in sounding work should usually be securely attached in a vertical position to a stake or a pile driven in the water or to the face of a wharf or a sea wall, or other suitable place, where it will

be at all times accessible, and where it can be easily read. In some instances, in tidal waters, a small piece of board is attached to the gage for a marker or indicator. When this is done the marker should be so arranged that it will float upon the water, directly in front of the gage, at all stages, the arrangement being such that the graduation designating the water level will show at the upper surface of the marker. The marker should be painted white; when it is used the gage reading can be quickly seen.

On rivers of widely varying stage it is usually not practicable to set in a vertical position a single gage that can be conveniently read at all stages of the water. In a case of this sort two or more gages, set separately, may be used; each gage is attached to a post or a tree, or other suitable object that is conveniently located. They should be so arranged that when the top of the lower gage is submerged the lower part of the next higher gage will show the proper reading.

In a case where the stream has sloping banks the gage may be set at a suitable inclination to conform to the slope of the bank. It should be attached to permanent objects or to stakes or posts driven firmly into the ground. It may be arranged in several sections, connected together, but of varying inclinations to conform to local changes of slope; such an arrangement is shown in Figure 47. No graduations should be marked on the rod until it has been properly secured in place. The graduations should then be determined by the aid of an engineer's level; they can be marked by painted lines, or by copper tacks, or by metal strips, as may be most convenient for use.

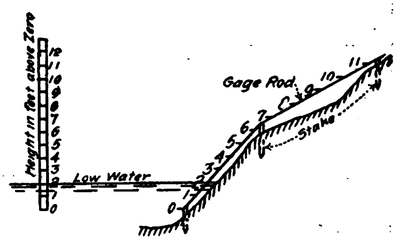

Fig. 47 Inclined Water Gage.

Automatic Gage. When a continuous record of the fluctuations of the water surface is required, an automatic or self-registering gage should be used. A simple form of automatic water gage, for use in tidal waters, consists of a float, which is enclosed within a perforated vertical box or case, and which rises and falls with the tide. The enclosing box, which is long enough to cover the entire range of the tide, has an opening near the bottom, through which the water enters; by this means the water surface inside the box is always the same as that outside and, not being affected by the motion of the outside water, is always smooth. The motion of the float, after being reduced by mechanism, is recorded by a scribe or

a pencil on a roll of paper, which passes at uniform speed over a cylinder revolved by clockwork. The path of the pencil on the paper indicates the stage of water during any given period of time of the observations.

Self-Reading Tide Gage. A form of automatic tide gage, which is called a self-reading gage, was devised by Mr. James H. Bacon, U. S. Assistant Engineer, for use in hydrographic work in Cumberland Sound. The arrangement comprised a rectangular-shaped structure, built at the edge of the water, and enclosing mechanism for operating the gage. The structure consisted of a room of cubical form, about 8 feet each way inside, and mounted on suitable supports, with its bottom 12 feet above the level of mean low water. On the east, west and south sides of the cube were painted circular dials of a pattern similar to that shown in Figure 48.

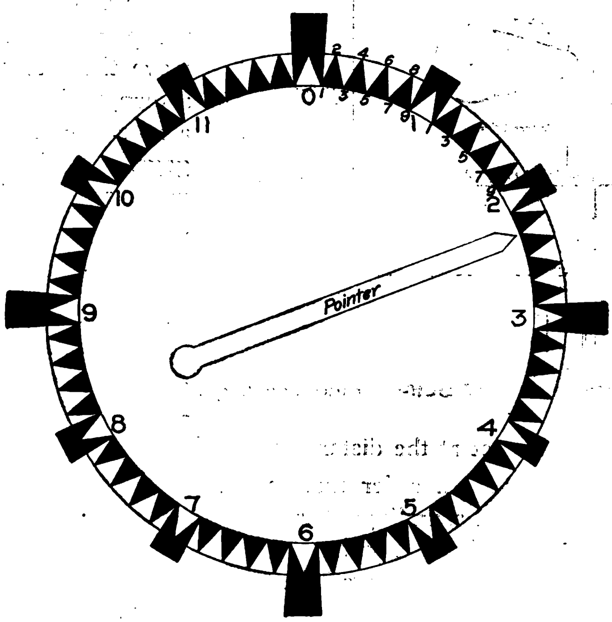

Fig. 48. Dial for Self-reading Tide Gage.

Each dial was provided with a large pointer or hand that was actuated by a float, being connected thereto by gearing, so that for a rise or fall of 1 foot the hand moved through exactly one-twelfth of the circle. Each dial was graduated into twelve 1-foot marks, the feet being subdivided into tenths, as shown. The position of the hand on the dial indicated at any time the exact height of tide;

the position shown in Figure 48 reads 2.3 feet above the zero point of the gage, which point is referred to mean low tide.

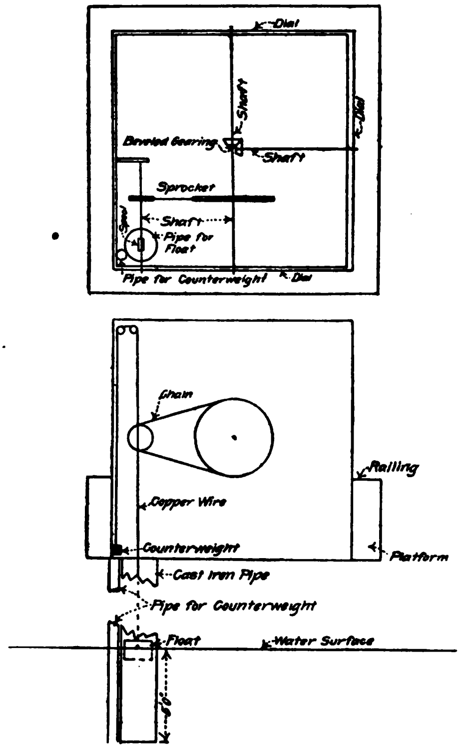

Fig. 49. Mechanism of Self-reading Tide Gage.

In Figure 49 is shown in plan and section the mechanism of this gage, adapted for a range of tide of from 5 to 8 feet. The gearing was so arranged that each shaft carrying a dial hand revolved once during a vertical movement of the gage float through 12 feet. The float was heavy enough to furnish the power necessary to move the mechanism as shown, and also to operate a recording tide gage. Ball bearings were used to reduce friction.

This gage could be read, under favorable conditions, a considerable distance; the height of tide could be determined from the dial to within 0.2 of a foot at the distance of 1 mile.

Gage Readings. In order that proper reductions may be determined for observed soundings it is usually necessary to observe and note the gage readings at suitable intervals during sounding work. When sounding in tidal waters it is customary to employ a tide gage reader, whose duties consist in reading and recording gage heights at intervals of from 30 minutes to 1 hour, or more, according to the stage of water and the range of the tide.

In the case of a lake or other similar body of water, where but little variation in height of water is liable to occur, gage readings may be necessary only at infrequent intervals. It is often the case that two readings a day, one in the morning and one in the evening, are sufficient. In some instances, however, a small lake is quickly affected by heavy rains or by the condition of tributary streams, and

rises and falls with considerable rapidity. Under such conditions frequent gage readings are required.

In a river that is subject to variations in stage the gage should be read with more or less frequency as may be required. If the water is rising or falling during the sounding work, gage readings may be necessary at hourly intervals or even oftener; ordinarily, however, two readings a day will be sufficient.

CHAPTER III.

Notes and Office Work—Sounding Book—Angle Book—Sounding Notes—Sextant Notes—Complete Notes—Tide Book—Platting Notes—Three-Arm Protractor—Hydrographic Maps and Charts.

The field notes taken during sounding operations are kept in various forms according to the methods employed in locating the soundings. When locations are made with one or two instruments on shore, or in the sounding boat, two general forms of notebooks are used; these are called, respectively, Angle Book and Sounding Book. For other methods of location the form of notes will depend upon the method used. For work in tidal waters, where a tide-gage reader is required, an additional form of notebook is used, called the Tide Book.

When soundings are located by means of time intervals, between known points, the field notes contain the depth and the exact time for each sounding. In this case the sounding notes are kept by the recorder in the sounding book, in the manner shown in Form 1. The notes taken in the boat are recorded in the first three columns on the left. After determining the lead line corrections and ascertaining from the notes of the tide-gage reader the corrections necessary for the stage of tide, the reductions are applied to the observed depths and the notes are completed as shown.

This form of notes is practically the same for all methods except the two methods of location that were last described. In all cases where used these notes are kept by the recorder in the sounding book; when completed, as just described, they may be kept in that form for permanent record.

The field notes taken by each of the observers who locate the soundings are entered in the angle book in the manner shown in Form 2, which represents a page from an angle book.

When soundings are located by one angle, measured on shore, two, and sometimes three, field books are required to contain the complete notes.

These comprise: 1, the sounding book, shown in Form 1, used by the recorder; 2, the angle book, used by the observer, and shown in Form 2. For work in tidal waters a third field book is required;

SOUNDINGS IN BENTON HARBOR.
Aug. 17, 1903.
JONES, Recorder. SMITH, Leadsman.

RANGE 1.

No.	Time	Soundings		Red. for Tide	Reduced Soundings		REMARKS
		Feet	10ths	Feet	Feet	10ths	
1	8:15	20	3	−1.1	19	2	(15 ft. from Sta. 27 of Shore Survey.)
2		21	6	−1.1	20	5	Lead line correction (+0.2) applied to all soundings.
3		23	2	−1.1	22	1	
4	8:16	22	1	−1.1	21	0	
5		21	4	−1.1	20	3	
6		21	7	−1.1	20	6	Hard bottom—Sand.
7	8:17	20	9	−1.1	19	8	
8		20	4	−1.1	19	3	
9		20	1	−1.1	19	0	Soft—Mud.

RANGE 2.

No.	Time	Soundings		Red. for Tide	Reduced Soundings		REMARKS
		Feet	10ths	Feet	Feet	10ths	
1	8:30	19	6	−1.3	18	3	Sounding 1 located by intersection from shore.
2		19	9	−1.3	18	6	Lead line correction, +0.2.
3		20	5	−1.3	19	2	
4	8:31	20	3	−1.3	19	0	
5		19	8	−1.3	18	5	
6		19	7	−1.3	18	4	

Form 1. Sounding Notes.

SOUNDINGS IN SABINE HARBOR.
Oct. 22, 1902.
JACKSON, Observer.

No.	Time	Angles		Reduced Soundings		REMARKS
		Deg.	Min.	Feet	10ths	
1	10:01	18	24			Soundings on Range 6. Inst. at Sta. 27 of Shore Survey. Numbers refer to the observed soundings.
2	10:02	20	12			
3	10:03	22	08			
4	10:04	24	10			

Form 2. Angle Book—1 Angle.

this is called the tide book, and it is used by the tide-gage reader. In Form 3 is represented a leaf from the tide-gage reader's note book, in which is shown the form of notes required to be kept. It is seen that there are columns in which to record the direction and force of the wind and also to enter the reduced readings of the tide-gage. In many localities the effect of the wind upon the water level is considerable under certain conditions of wind and tide. In such cases it is necessary to take into account the variations caused in the height of the water surface thereby and to make the necessary reductions.

For convenience in platting the reduced soundings are frequently entered in the angle book in the two columns shown; in such cases the angle book forms a complete record.

When soundings are located by two angles measured on shore, each observer uses an angle book in which to enter his field notes. These are kept in the manner shown in Form 2, while the recorder's notes are kept as shown in Form 1. In non-tidal waters the three sets of notes that have been described are all that need be used. For work in tidal waters a tide-gage reader will be required, whose notes are kept as shown in Form 3. The complete notes may be condensed for convenience in the manner shown in Form 4.

When two sextants are used in locating soundings the notes of the recorder and of the tide-gage reader kept as shown in Forms 1 and 3 respectively. Each sextant observer enters his notes in his field book, noting for each sounding the number, the time and the sextant angle to two of three selected shore objects. In Forms 5 and 6 are shown the field notes of two sextant observers, locating identical soundings. The two sets of notes may be condensed into one in a manner similar to that explained for transit observations.

For soundings located with transit and stadia the form of field notes taken by the observer is practically the same as for similar stadia observations on land. Since such forms of notes are generally familiar to engineers and surveyors it is not considered necessary to illustrate them here. The other forms of notes, which are kept by the recorder and the tide-gage reader, are practically the same for most methods of sounding location.

When soundings are located by magnetic bearings, the forms of notes used by observers is very similar to that used for sextant observations. The only essential difference in form is, that for compass work the word "bearings" is substituted for the word "angles" in Forms 5 or 6, and the several bearings are given instead of angles.

OBSERVATIONS OF TIDES AT LIGHTHOUSE WHARF.

Year, 1903. Month, Aug. Date of Month, 17.

Mean Time of Observation		Reading of Tide Gage		Wind		Reduced Readings		REMARKS
Hrs.	Min.	Feet	Dec's	Direc.	Force Miles per Hr.	Feet	Dec's	
8	00	1	00	N. W.	10			Light Wind from N. W., changing to W.
8	30	1	55	N. W.	10			
9	00	2	15	W.	10			
9	30	2	70	W.	10			
10	00	3	35	W.	10			

Form 3. Tide Book.

SURVEY OF MOBILE BAY.

June 20, 1902.

DAVIS & WILLIAMS, Observers. TAYLOR, Leadsman.

CORTRIGHT, Observer.

No. 1. Davis—Zeros to Sta. B. H. & B. Transit, No. 3312.

No. 2. Williams—Zeros to Sta. A. B. & B. Transit, No. 2408.

No.	Time	No. 1 Angles		No. 2 Angles		Reduced Soundings	REMARKS
		Deg.	Min.	Deg.	Min.		
1	9:25	9	58	13	20	23.8	
2	9:26	19	12	25	26	26.2	
3	9:27	27	32	35	28	30.6	
4	9:28	35	30	44	22	35.5	

Form 4. Complete Notes.

SURVEY OF ONSLOW BAY.

May 23, 1902.

WILLIAMS, Sextant No. 1.

MASON, Recorder. HARRIS, Leadsman.

No.	Stations	Angles		REMARKS
		Deg.	Min.	
1	23-25	37	12	Sta. 23.—Lighthouse.
2		39	59	Sta. 25.—Church Spire.
3		42	02	
4		44	00	

Form 5. Sextant Notes.

SURVEY OF ONSLOW BAY,
May 23, 1902.
JACKSON, Sextant No. 2.
MASON, Recorder. HARRIS, Leadsman.

No.	Stations	Angles Deg.	Angles Min.	REMARKS
1	25-27	44	39	Sta. 25.—Church Spire.
2		42	51	Sta. 27.—Factory Chimney.
3		40	55	
4		39	40	

Form 6. Sextant Notes.

SOUNDINGS IN MORRIS CANAL.
Monday, June 6, 1904.
Previous to Dredging Work.
JONES, in charge. SMITH, WILLIAMS, Assistants.

Sta.	Soundings											REMARKS
137	$\frac{00}{4}$	$\frac{3.0}{7}$	$\frac{6.0}{13}$	$\frac{5.6}{18}$	$\frac{5.8}{22}$	$\frac{5.4}{27}$	$\frac{4.8}{32}$	$\frac{5.3}{37}$	$\frac{5.8}{40}$	$\frac{3.0}{47}$	$\frac{00}{50}$	Water surface is datum. Depths are expressed in numerator, distances are expressed as denominator; they are in feet and are measured from the station stakes from left to right.
138	$\frac{00}{3}$	$\frac{4.0}{7}$	$\frac{6.4}{15}$	$\frac{5.8}{21}$	$\frac{6.9}{26}$	$\frac{6.2}{31}$	$\frac{7.3}{36}$	$\frac{4.5}{44.5}$	$\frac{00}{49}$			
139	$\frac{00}{3.5}$	$\frac{3.5}{7}$	$\frac{6.9}{14}$	$\frac{7.4}{19.5}$	$\frac{6.4}{27}$	$\frac{7.2}{34}$	$\frac{6.5}{41}$	$\frac{3.5}{46}$	$\frac{00}{49.5}$			

Form 7. Sounding Notes.

SOUNDINGS IN MORRIS CANAL.
Thursday, June 9, 1904.
After dredging.
JONES, in charge. SMITH, WILLIAMS, Assistants.

Sta.	Soundings						REMARKS
137	$\frac{00}{4}$	$\frac{8.2}{12}$	$\frac{8.3}{22}$	$\frac{7.9}{32}$	$\frac{8.2}{42}$	$\frac{00}{50}$	Water surface is datum, distances are from station stakes; they are from left to right.
138	$\frac{00}{3}$	$\frac{8.3}{11}$	$\frac{8.2}{21}$	$\frac{8.0}{31}$	$\frac{8.1}{41}$	$\frac{00}{49}$	
139	$\frac{00}{3.5}$	$\frac{8.1}{11.5}$	$\frac{8.1}{21.5}$	$\frac{8.2}{31.5}$	$\frac{8.1}{41.5}$	$\frac{00}{49.5}$	

Form 8. Sounding Notes.

When soundings are located by direct measurement on the ice the field methods are similar to those used in land surveys. In such cases no particular form of notes need be specified for recording sounding locations since the ordinary forms of notes used in surveys are suitable for this purpose.

For soundings that are located upon a fixed range, designated by a graduated wire or rope, the notes may be kept in a form similar to that used for recording cross-section notes. A good form for recording notes of this kind is shown in Form 7. The notes there shown represent soundings across the canal shown in Fig. 45, at three of the stations shown. The soundings were made previous to dredging operations, the object being to ascertain the depth of dredging required, and also to determine the quantity of material required to be removed from the channel.

In Form 8 is shown the notes of soundings made over the same ranges after dredging operations were completed. These latter soundings were made to ascertain if sufficient dredging had been done to make the channel conform to the required dimensions.

Special Forms of Notes. For locations of soundings made by Cooper's method, in which two leadsmen are employed, as previously described, a special form of notes is used. In order to explain clearly the methods used for keeping notes a full set of notes will be given; they are field notes from an actual survey made under the supervision of Mr. Cooper.

Sounding Book. The form of sounding notes taken is shown in Form 9. The notes as shown are complete, as regards depths; they show the time of making located soundings, gage readings and observed and reduced soundings. On the right-hand page is shown the test measurements of the two lead lines that were used.

Transit Books. The two sets of location notes taken are shown in Forms 10 and 11. They contain the number of the range or sounding line, the time and number of each located position, also the angles read to positions of observed soundings. In this instance one of the observers read the tide-gage and entered the readings in the column headed "Gage." The three sets of notes were kept in ordinary transit books, 4½ ins. by 7 ins. in size.

Bacon's Method. In Form 12 is shown the form used for recording sounding notes that were taken when Bacon's method was used. As indicated, two sextants were used, the observations being taken to four known objects on shore, as explained on page 57, and as illustrated in Figure 35.

ESTIMATE SURVEY, LONG ISLAND CROSSING.

May 16, 1904.

P. N. STRONG, in charge. A. S. HARTRIDGE, Recorder.

LINE No. 42

No.	Time	Gage	Soundings: Fred. Jones	Soundings: Chas. Anderson	Reduced Sdgs.	REMARKS
1	10:37		17.2		12.2	Howard on Sta. Wing
				17.1	12.3	Dam, No. 33.
			17.3		12.3	Ostrom on Sta. Venus
				17.1	12.3	Point.
			16.9		11.9	Ostrom reading Gage.
				17.4	12.6	
2	10:38		18.2		13.2	
				19.2	14.4	
			18.1		13.1	
				20.7	15.9	
			20.0		15.0	
				21.0	16.2	
3	10:39		23.9		18.8	
				26.1	21.3	
			26.1		21.0	
				26.2	21.4	
			26.3		21.2	
				25.7	20.9	
4	10:40	4.9	25.3		20.2	
				25.6	20.8	
			25.1		20.0	

TEST OF LEAD LINES.

Fred. Jones Lead		Fred. Jones Tape	C. Anderson Lead		C. Anderson Tape
12	=	11.9	12	=	12.1
14	=	13.9	14	=	14.1
16	=	15.9	16	=	16.1
18	=	17.9	18	=	18.1
20	=	19.9	20	=	20.1
22	=	21.8	22	=	22.2
24	=	23.8	24	=	24.1
26	=	25.8	26	=	26.1
28	=	27.7	28	=	28.1
30	=	29.7	30	=	30.1

Form 9. Sounding Book.

ESTIMATE SURVEY, LONG ISLAND CROSSING.

May 16, 1904.

Inst. on Sta. Venus Point. Zero to Sta. Wing Dam, No. 3.

E. OSTROM, Transit No. 1.

No. of Line	Time	No. of Position	Angle: Deg.	Angle: Min.	Gage	REMARKS
42	10:37	1	278	42		Gage read at Venus Point,
	38	2	282	35		mean low water on Gage
	39	3	285	49		=2.0.
	40	4	Dredge in way		6.9	
	41	5	291	51		
	42	6	294	00		
	43	7	296	15		

Form 10. Angle Book.

ESTIMATE SURVEY, LONG ISLAND CROSSING.
May 16, 1904.
Inst. on Sta. Wing Dam, No. 33. Zero to Sta. Venus Point.
R. S. HOWARD, Transit No. 2.

No. of Line	Time	No. of Position	Angle Deg.	Angle Min.	Gage	REMARKS
42	10:37	1	328	45		Zero to Sta. Venus Point.
	38	2	326	01		
	39	3	323	50		
	40	4	322	05		
	41	5	320	23		
	42	6	319	14		
	43	7	317	57		

Form 11. Angle Book.

LINE NO. DATE
BACK RANGE ON

No.	Time and Tide	Sounding	S'd'g cor'ct'd for lead line error	S'd'g cor'ct'd for tide	Angles Sextant		REMARKS
					A-B		
1	8.46 + 5.9	16.3 h.	15.4	9.5	98-46		
		17.2	16.3	10.4			
		18.1	17.2	11.3			
		19.0 m.	18.1	12.2			
		20.9	19.9	14.0			
		21.8	20.8	14.9			
2	8.47 + 6.0	22.7 sd.	21.7	15.7	99-45		
		23.6	22.6	16.6			
		24.5	23.4	17.4	C-D		
3	8.48 + 6.0	25.4 m.	24.3	18.3	73-40		
		26.3	25.2	19.2			
		27.2	26.1	20.1			
4	8.49 + 6.0	28.1	26.9	20.9	72-35		
		29.0	27.8	21.8			
		29.9	28.7	22.7			
5	8.50 + 5.9	30.8	39.6	23.0	71-30		
		e	+		c		

NOTE.—Sextant Stations used one. A. & B. and C. & D. Form can be used for either Transit or Sextant work.

RECORDER:—
OBSERVER:—

Form 12. Sounding Book.

Various other forms of notes than those that have been shown are used for recording sounding observations. Such variations in form depend largely upon the individual preference of the surveyor for some particular form of notes, as well as upon the methods used in performing the work.

Platting Soundings.

After soundings have been made and located they must be platted in their correct positions upon a map or chart, in order to properly designate the sub-aqueous contours or to show the configuration of the bottom, as may be required. In many instances, especially when a large area is sounded, many more soundings are made than are necessary for mapping purposes. The reason for this is that since the bottom is not visible, the entire area is thoroughly sounded in order to avoid missing important changes of slope. In platting, however, it is customary to show only characteristic soundings; that is, such soundings as will show with sufficient accuracy the depths of a given area and the conformation of its bottom.

In platting soundings upon a map or chart, the position of a sounding is shown by a dot, lightly marked with a pencil. The depth of each sounding is written in ink directly over the point designating that sounding, after which the pencil mark is erased.

The methods employed for platting soundings vary according to the methods by which they are located. In a case where soundings have been located on a range whose position is known, a pencil line, representing the range, is drawn to scale in its correct position on the map or chart. Then, if the positions of given soundings are known with respect to the extremities of the range, and the distances between intermediate soundings are also known, the positions of the known soundings are marked on the pencil line, and the positions of the intermediate soundings are determined by scale.

If soundings have been located on a range by intersections, either by one shore angle or by two shore angles, they can be platted in the following manner: The range is first laid off on the map, as previously described; the angles from the shore points to the respective located positions are then measured on the map with a protractor, or they may be determined by natural tangents. Lines defining the several angles are drawn in pencil to intersect the line representing the range. Each intersection will designate the position of an observed sounding; the positions of intermediate soundings can then be scaled.

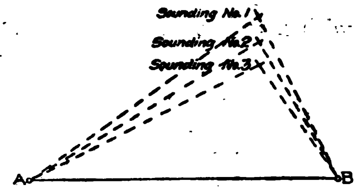

Fig. 50. Platting Soundings by Intersection.

If soundings have been located by two intersecting lines of sight, from the extremities of a measured base, they may be platted in the following manner: The base line is first drawn to scale, in its proper position on the map, and from each extremity, pencil lines are drawn in the same directions and at the same angles as those measured in locating the respective soundings. The intersection of any two such lines, representing the lines of sight from opposite ends of the base to the position of any given sounding, will locate that sounding on the map. Thus, in Figure 50, let A-B represent a given base line on a map or chart. The dotted lines, A-1, A-2, A-3, and B-1, B-2, B-3, representing the lines of sight to three given soundings, are laid off at the measured angles recorded in the notes. The intersections of the respective lines are the locations of the corresponding soundings 1, 2, and 3.

Another way to plat soundings that have been located by intersection from the two opposite extremities of a given base, is as follows: For each observed sounding, the respective distances from its located position to opposite ends of the base are calculated and noted. This can be done by trigonometry, since for each location, a side and two adjacent angles of a triangle are known, and the other two sides, representing distances from the extremities of the base to the located position of the sounding, can be calculated by solving the triangle. The base line having been drawn to scale, in its proper position on the map, its extremities are used as centers, from which intersecting arcs are drawn with the corresponding calculated distances as radii; the point of intersection of the two arcs marks the position of the sounding.

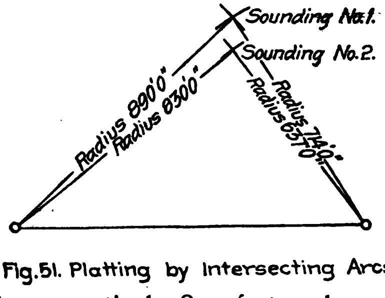

Fig. 51. Platting by Intersecting Arcs.

This method of platting soundings is illustrated in Figure 51, in which A-B represents the base and A-1, B-1, are the two calculated distances to the located position of sounding 1.

Example. Let the base line A-B equal 1,030 feet, and the calculated distances from A and B to the position of sounding 1 be respectively 890 feet and 714 feet. Then, with A as a center

and with a radius of 890 feet, draw in pencil a circular arc, in the approximate location, and long enough to cover the position of the sounding. Next, with B as a center and with a radius of 714 feet, draw another circular arc, intersecting the first; the intersection of the two arcs locates the sounding on the map.

This method of platting involves a long and tedious process and is seldom used for locating soundings. It may be used as a check upon important locations that have been platted by a more rapid method; or for the purpose of locating important objects, such as buoys, reefs, etc.

When soundings have been located by means of sextant angles from the sounding boat, to three fixed points on shore, the most convenient way to plat them on a map, upon which the three shore points have been previously platted, is by the use of three-arm protractor. Since this instrument is exclusively used for platting soundings that have been located by sextant angles, a description of it will be given here.

Three-Arm Protractor.

This instrument, which is sometimes called a station pointer, consists of a graduated arc to which is attached three arms, one fixed

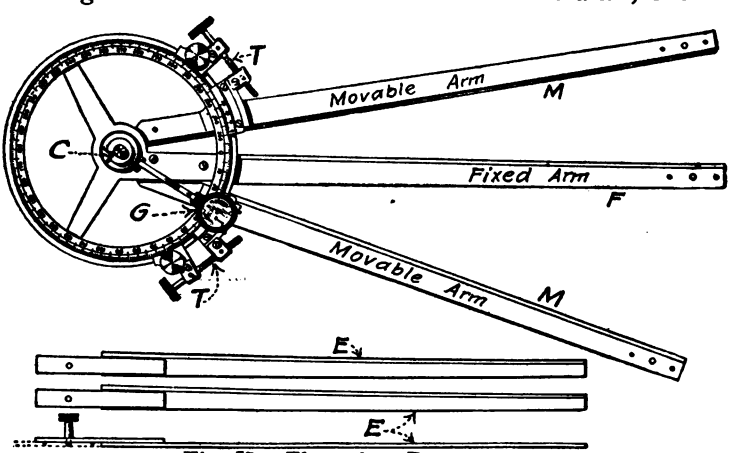

Fig. 52. Three-Arm Protractor.

and two movable, the two latter revolving about a center which is common to the three arms. The two movable arms are located, one on either side of the fixed arm; they have their inner edges beveled, as shown in Figure 52. The circle is divided into 360 degrees; the fixed or zero arm, F, is set so that its beveled edge is projected through the zero mark on the circle, and also through the center, C, of the instrument. The two movable arms, M, M, are provided with

verniers reading to single minutes; also with clamp and tangent screws, T, T, as shown. A magnifying glass, G, is pivoted and hinged to the center of the circle, and moves parallel to the graduations.

Centers. Each instrument is usually provided with three interchangeable cylindrical centers. One center is provided with a glass bottom, upon which is etched two lines, intersecting at the center of the circle; this is used for the purpose of identifying locations after they have been made. Another center has a transparent, horn bottom, with a hole through its exact center; when this is used the locations are dotted through the hole with a pencil point. The third form of center has a spring needle point, which is directly over the center of the circle; this is used for pricking the center on the map or chart, when the protractor is in position.

Size. Three arm protractors are made in several different sizes; they are usually provided with extensions, E, E, E, for lengthening the arms when required. The graduated circle varies in size from 5 ins. to 6½ ins. in diameter, and the arms are made from 15 ins. to 18 ins. long. When extensions are used, the arms extend from 25 ins. to 27½ ins. beyond the edge of the circle.

Testing. Before making extensive use of a three-arm protractor it should be tested for centering and for accuracy of graduation. To test for centering: First bring the two movable arms close up against the stationary or zero arm; then clamp both movable arms, one tightly and the other just tight enough to require a slight effort to move it. Move this arm entirely around the graduated circle and then back again to its former position. Clamp it tightly, then loosen the other movable arm and proceed in the same manner as with the first one. If the movable arms meet with slight and uniform resistance while being revolved, the instrument is well centered. If, however, the resistance is uneven, causing the arms to stick or bind, at some places, the instrument requires adjustment or proper centering.

In testing for graduation: First set one of the movable arms at 180° and clamp it; then lay the instrument flat upon a sheet of drawing paper and draw a pencil mark along the edge of the clamped arm, also along the edge of the zero arm, and mark a point through the center of the instrument. Remove the protractor and place a straight edge on the paper so it will coincide with the first pencil line; it should also pass through the central point, and coincide with the line which was drawn along the edge of the zero arm. Make the same test with the other movable arm. A similar test can

also be made by clamping the two movable arms, one at 90° and the other at 270°, and also at other selected points around the circle that are 180° apart.

Use of Three-Arm Protractor. In using a three-arm protractor to plat the positions of soundings that have been located by sextant angles to three known shore points, the following method is that commonly employed. First plat in their correct positions the three shore points; then, in order to plat the position of a given sounding, set the movable arms to the two observed angles and clamp them in position. Then place the instrument on the chart so that the edges of the three arms will coincide with the platted positions of the three shore points; the center of the instrument being in a position on the map corresponding to that of the boat on the water at the time the sounding was located. The center of the instrument will then represent the position of the sounding, and a point is dotted or pricked through the center of the instrument on the map. The protractor is set in the same way for each observed sounding and the process just described is repeated in platting individual locations for successive soundings.

Method by Use of Tracing. It is often the case that the positions of soundings that have been located by sextant angles require to be platted without the use of a three-arm protractor. A good way to plat soundings so located is as follows: For any given sounding, draw on tracing paper or tracing cloth, three lines passing through a common point, and including between them the two observed angles for that sounding. Place the tracing on the map in such a position that the common point will be in a position corresponding to that of the sounding boat on the water, and so that the three lines will pass through the three platted points. The point of intersection of the three lines will then indicate the position of the sounding on the map; it should be pricked through the tracing or otherwise marked on the map. Since, when this method is used, it is necessary to practically make a protractor for each location, the method is seldom employed, especially when many soundings are to be platted.

Method by Calculation. Observed locations, made by sextant angles, can be platted by calculating the respective distances from the shore points, that have been previously located, to the sounding boat or to the given located point. A method of calculating such distances has been given in the solution of the three point problem, previously explained. The distances, having been found, may be used as radii and, with the respective shore points as centers, arcs

can be drawn to a common intersection, thus locating the sounding. If preferred, the angles between the base line and the respective lines of sight for a given sounding, may be laid off and lines bounding these angles drawn to a common point of intersection, which will locate the sounding. This process is both tedious and laborious; it is not given as a method suitable for practical use in platting soundings. It is adapted for use where positions are to be platted with considerable accuracy, or where it is necessary to check the location of an important object, such as a buoy, a wreck, a sunken rock, or other object of similar importance.

Compass Locations. When soundings have been located by compass bearings, observed in the sounding boat, their positions can be platted in the following manner: The two fixed points to which observations have been made are first platted in their correct positions on the map. Then, in order to locate the position of a given sounding, pencil lines, having the bearings given in the notes for that sounding, are drawn in their proper relative positions through the two platted points. The intersection of the two lines thus drawn locates the sounding on the map.

Bacon's Method. Soundings that have been located by Bacon's method, which has been described, can be platted accurately and rapidly when suitable preparations are made. In order to facilitate platting the positions of soundings located by this method, for each locality sounded, a protracting sheet should first be drawn to the required scale, upon a skeleton or outline map of the area sounded. The protracting scale consists of a series of arcs, each arc subtending a given angle, and passing through the extremities of the platted base line. The ranges are drawn radial or parallel, as the case may be; the completed scale will resemble Figure 34, Figure 35 or Figure 36, according to the method used in laying out the base lines and ranges. The base lines, ranges and arcs should be platted to some convenient scale upon a sheet of drawing paper. In order to prevent shrinking or wrinkling the paper used should be pasted smoothly on a drawing board which has previously been coated thoroughly on both sides with shellac. The outline map and the protracting scale should be drawn in their proper relative positions in india ink, thus forming a basis to which all subsequent surveys over the same area may be referred. The surveys should be platted on tracing cloth, to the same scale as that used for the skeleton map. In order to plat the soundings made in the successive surveys, the tracing is laid over the skeleton map in such a manner that corresponding points on both maps will coincide. The position of each observed

sounding can then be quickly located from the field notes on the skeleton map and marked on the tracing.

For example: If a sounding has been located by observations to two base lines, as illustrated in Figure 35, and the angular values are as follows: Angle to extremities of base A-B—63° 00′; angle to extremities of base C-D—56° 00′, then the point of intersection of the arc through A-B, subtending 63°, with the arc through C-D, subtending 56°, is readily found and locates the sounding at once. If the soundings have been made on radial ranges, as illustrated in Figure 36, or on parallel ranges, as illustrated in Figure 37, they are platted by noting on the map the intersection of the given range with the arc corresponding to the angle measured. Thus, a sounding made on a radial range, as, for example, range 1, Figure 36, whose angular measurement is 54°, is readily located at the intersection of these two factors at the point marked x. Soundings made on parallel ranges can be located and platted in a similar manner. For intermediate angles between platted arcs, soundings can be platted by interpolating distances proportional to the angular interval.

Cooper's Methods. A method of platting with great rapidity the positions of soundings that have been located by intersection from shore stations has been devised by Mr. A. S. Cooper, whose method of locating soundings has been previously described. Two general cases are contemplated, each requiring different treatment. In a case where a number of successive surveys are required over the same area, and the successive locations are made from the same base, the following method is used: An outline map of the area to be surveyed is platted on drawing paper, with the base line drawn to scale, in its proper position. Two protractors are then drawn, with their respective centers at the two extremities of the base line, or corresponding to two fixed stations. These protractors are drawn sufficiently large to cover the sounded area; they are divided into ¼ degrees and the division lines are drawn to intersection. This is called the protractor sheet; its arrangement is illustrated in Figure 53, in which the extremities

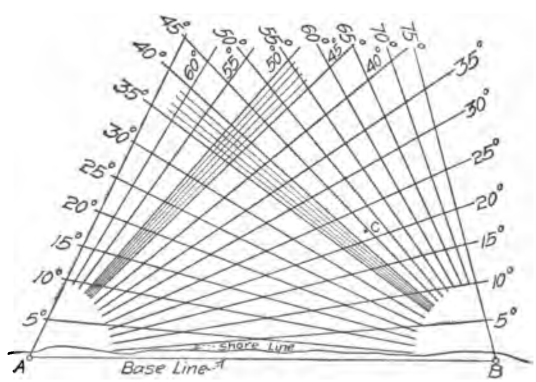

Fig. 53. Protractor Sheet.

A and B of the base line A-B are the respective centers of the two protractors shown. The graduations for 5° are marked with heavy black lines, those for degrees with lighter lines, those for half-degrees with full red lines, and those for quarter-degrees with dotted red lines. The survey map is drawn on tracing cloth to the same scale as the skeleton map; it shows the base line, the shore line and other necessary topographic features. The skeleton and the survey maps are so drawn that when the tracing is placed over the outline map, corresponding lines on each will coincide. In platting soundings, located by intersections from the extremities of the base, within the area covered, the tracing is laid over the outline map so that corresponding lines will coincide; any given sounding is then platted at the intersection of the two lines on the protractor sheet corresponding to the observed angles of location. Thus, referring to Figure 53 when the observed angles at A and B to a given sounding are respectively 21° 30′ and 44° 15′, the position of the sounding is seen to be at C. This method is adapted for platting locations made in a circumscribed area; it can be used only for the area for which it is designed.

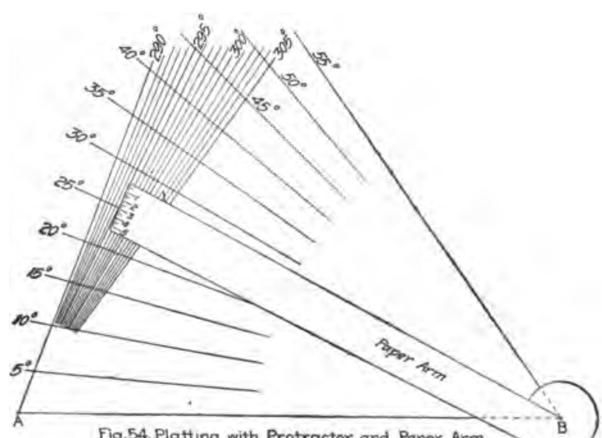

Fig. 54. Platting with Protractor and Paper Arm.

The following method, also devised by Mr. Cooper, is adapted for platting rapidly and accurately the positions of soundings, located by intersections from a known base. The survey map is drawn to scale on tracing cloth, with the base line platted in its proper position. When soundings are to be platted, the survey map is placed upon a drawing board or table, with one of the instrument stations, as A, Figure 54, directly over the center of a large paper protractor, that has been graduated to quarter-degrees. The map and pro-

tractor are fastened to the drawing board, after adjusting an even 5° line on the protractor to coincide with the base or zero line of the survey. The graduations of the protractor are numbered at 5° intervals to correspond with the azimuth angles; these numbers are written in pencil on the survey map so as not to disfigure the protractor for future use. From the other instrument station, as at B, Figure 54, radial lines are drawn at intervals of 5°, with the zero of the graduations on the base A-B. These lines are in pencil; they are of suitable length, and are sufficient in number to cover the area sounded. Over station B is fastened a long paper arm, so arranged that it will revolve around the station as a center, with one edge passing through the center. This paper arm is secured in place by a needle passing through its center; it is of sufficient length to reach the position of the most distant sounding. The outer end is provided with a vernier, reading to single minutes.

In locating the position of a given sounding, the line on the protractor designating the angle read from A is noted; the paper arm is then revolved until its vernier marks the angle read from B. The position of the sounding is found at the intersection of the fiducial edge of the paper arm with the designated line on the protractor. For example, a sounding whose observed angular values at A and B are respectively 302° 30′ and 27° 55′ is located at position 1 in Figure 54.

Hydrographic Maps and Charts.

Maps of hydrographic surveys are made in a similar manner to that used in making ordinary topographic maps. An outline map of a lake or river survey should show the lines and angles of the survey, the triangulation stations, if any, also the shore line and such details of the adjacent topography as may be considered necessary.

A complete hydrographic map of a river, lake, reservoir or of other bodies of water, shows, in addition to the outline of the water, and the surface topography, the shape or configuration of the bottom or of the submerged portion of the containing basin or valley.

In the case of a proposed reservoir, whose area is to be subsequently flooded, a regular topographic map is made, showing contour lines at required intervals and other necessary details.

In the case of an existing body of water, in which soundings have been made, lines of equal depth, corresponding to contour lines on a topographic map, are drawn. These lines are located on a hydrographic map or chart in the following manner: The soundings are first platted, according to one of the methods that have been described, and the depth of each sounding is written directly over

its located position on the map. The lines of equal depth, or the sub-aqueous contours, are then located and drawn according to the methods used in platting contours on a topographic map. The length of the contour interval usually depends upon the importance of the survey, the frequency of the soundings and the degree of accuracy required.

Navigation Charts and Maps. Navigation charts are intended for use as aids to navigation; they usually contain such information as is useful and important for navigation purposes. A complete chart of this kind, showing a harbor, coast or river, usually contains triangulation stations and important details of topography adjacent to the shore. In addition, there are shown lighthouses, beacons, wharves, breakwaters and other objects of like character; also rocks, reefs, sunken wrecks, bars and other dangers and obstructions to navigation. The position of a navigable channel is indicated by contours showing required depths.

A hydrographic map or chart of a navigable river should show the following details:

1. The position of the shore line on either side of the stream and such adjacent topography as may be required.

2. The location of islands, sand bars, rocks, etc., or any other objects of similar character that may be within the stream limits.

3. The outlines of the navigable channel as defined by the curves of equal depth, corresponding to the required depth.

4. The locations and depths of soundings and sub-aqueous contours corresponding to lines of equal depth, drawn at such contour interval apart as may be required.

The shore line is usually defined by the position of the water line at ordinary low water, or at the normal stage of the river. In cases where the banks are steep and sharply defined, the top of the bank may be shown, in addition to the low water line. In the case of a river with gently sloping banks the positions of the high and low water lines may be some distance apart, and in such a case both water lines may be shown.

The positions of islands, sand bars, shoals, etc., are shown in outline. Islands and objects that are above the ordinary water level are shown by full lines. The topography thereon is shown in the same manner as that on shore. Sand bars, shoals, etc., are usually shown by dotted outlines, with heights above or depths below the plane of reference written in figures at the proper places. In cases where the surface is above the plane of reference, the

minus sign is prefixed to figures indicating elevations to denote that such elevations are above and not below the datum.

The curves of equal depth, indicating the channel lines, and the sub-aqueous contours, correspond to contour curves on ordinary topographic maps, and are drawn in a similar manner. In the case of sub-aqueous contours it is customary to indicate different depths by characteristic lines, a special form of line being used to designate each depth shown. The forms commonly used in drawing lines of equal depth are as follows:

For the shallowest contour: ——— . ——— . ———

For the contour next in depth: ——— . . ——— . . ———

For the contour next in depth: ——— . . . ——— . . . ———

and so on for successive contours.

In addition to such details as have been described, the direction of the current is shown by an arrow and the directions of true and magnetic north are shown by suitable symbols.

In many cases it is considered advisable to show the positions of survey stations and sounding ranges on a hydrographic chart. This practice, however, is not common, especially in cases of charts intended for navigation purposes alone.

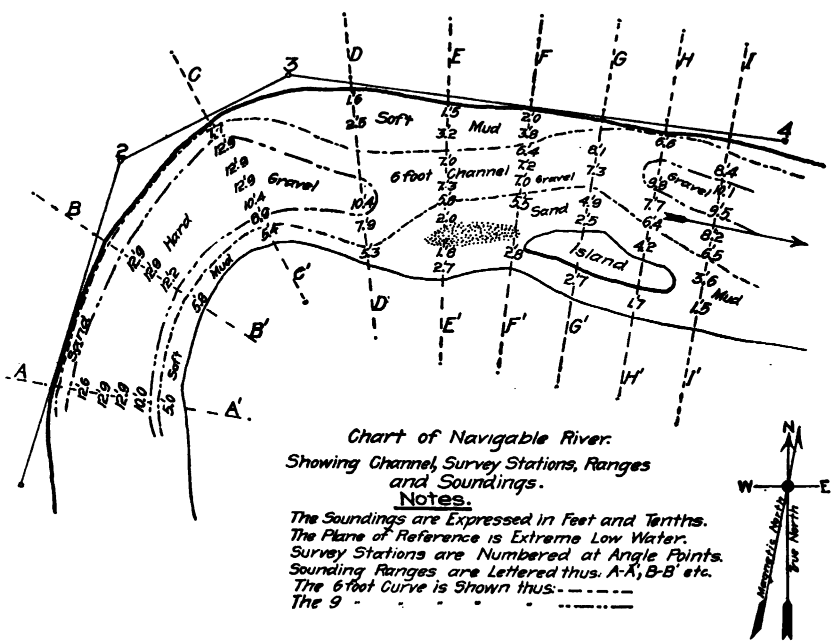

Fig. 55. Hydrographic Chart of River.

Hydrographic Chart of River. In Figure 55 is given a hydrographic chart of part of a navigable river, showing the various details that have been described, including sounding ranges, depths and limits of channel. The lines of survey are drawn in light, full lines, the ranges are shown by broken lines; the angle stations are numbered consecutively down stream, and the ranges are designated by letters of the alphabet, as shown. Depths of soundings are expressed in feet and tenths at located positions of respective soundings.

The soundings were made on ranges across the axis of the stream. They were located by two angles measured on shore, according to the method previously described. In this case the survey line between adjacent angle stations was used as a base, an observer with a transit being located at the angle point at either end of the base that was being used. After locating all soundings to which good intersections could be had from a given base, the upper transit was shifted downstream, one station beyond the other instrument, and the survey line between the two stations was used as a new base for locating soundings. This process was continued until the entire area had been sounded.

The outline of the navigable channel and the successive depth contours are each indicated by a characteristic line, such as has been described. The character of the bottom is written at such places on the chart as correspond to the points where samples were obtained during the sounding work.

Hydrographic Chart of Coast. A hydrographic chart of a harbor or of an entrance to a bay, is made in a manner somewhat similar to that described for a navigable river. In making a chart of this nature such details and information should be placed thereon as has been specified for navigation or hydrographic maps and charts in general. Lines of equal depth, indicating sub-aqueous contours, are drawn at the required interval apart. When required, the positions of ranges, range points and of angle stations on the survey line are also shown.

In Figure 56 is given a hydrographic map of the entrance to a bay. The original chart from which this map was taken is contained in the Annual Report for 1897 of the Chief of Engineers, United States Army, having been made from actual surveys. In this case, for simplicity, many of the soundings shown on the original chart have been omitted, only characteristic soundings being shown. This is a good example of the use of radial ranges, the soundings having been made on range lines radiating from the light-

house which is shown on the North Spit, and which was used as a central range signal. The depths of soundings are given in whole feet and the sub-aqueous contours are indicated by characteristic lines in a manner similar to that used for the river chart.

The two charts that have been illustrated and described are fair types of this class of work and serve to show in a general way how such maps or charts are made. There are various methods of filling in details and of expressing information on hydrographic maps and charts. These methods vary in minor details according to local practice and the object for which a given map is intended. When such maps are made for ordinary engineering purposes, as for indicating improvements to a channel, or for projecting a new channel, or for showing proposed improvements, etc., depths are generally expressed in whole feet or in feet and tenths of a foot, and contours are usually drawn at intervals of from 3 to 6 feet, as in the two charts given, or at closer intervals when required.

For navigation charts, depths are commonly expressed in feet to the nearest quarter of a foot, up to a certain depth, which is usually 24 feet or four fathoms; when this limit is passed depths are expressed in fathoms. The deepest contours are usually drawn at intervals of one fathom, or 6 feet, to the required limit.

CHAPTER IV.

MEASUREMENT OF DREDGED MATERIAL—MEASUREMENT IN PLACE—MEASUREMENT IN SCOWS—SURVEY TO DETERMINE CAPACITY OF A LAKE—METHOD BY CONTOURS—METHOD BY CROSS-SECTIONS.

When a channel is to be deepened or an excavation is to be made under water, the work is ordinarily done by dredging or other similar methods, and it is customary to determine by suitable means of measurement the depths to be obtained and the quantity of material to be excavated. Such measurements are usually made by soundings, which are made and located according to such of the methods that have been described as may be suited to the case.

In most cases the area involved is sounded both before and after dredging operations, the second measurement being made to ascertain if required depths have been attained, also to obtain data for computing the quantity of material dredged. In some cases the second series of soundings, made after the completion of dredging operations, is simply for the purpose of determining depths; in such cases the quantity of material excavated is usually measured in scows or barges. When dredged material is measured in place by means of soundings, the operation is called "Measurement in Place." When it is measured in scows or barges the operation is called "Scow Measurement"; both methods of measurement will be discussed and explained in order.

MEASUREMENT IN PLACE.

In measuring material in place, by means of soundings, it is important that corresponding soundings, made at successive periods, shall be in the same positions; or else that the two series of soundings shall be made at such points as will correctly indicate the differences in elevation of the bottom at suitable points. In calculating the volume of material indicated by the difference in heights shown by the two sets of measurements, methods of computation similar to those used for calculating earthwork, are used. Thus, for example, when material is dredged from a canal, the excavation is calculated as for a railroad cutting; when a large area is dredged,

the excavation is divided into figures, most convenient in shape for computation, and the ordinary rules of mensuration are applied.

For example, it is required to calculate the quantity of material dredged in a canal, from sounding notes that were taken before and after dredging; the notes used will be those given in Forms 7 and 8. In this case three sections are shown, with an interval of 100 feet between adjacent sections. These correspond to 100-foot stations in a railroad cutting, and the quantities are computed in a similar manner to that used for earthwork computations in railroad work.

The two sets of soundings at each station are platted together on cross-section paper, as shown in Figure 57. In this figure the

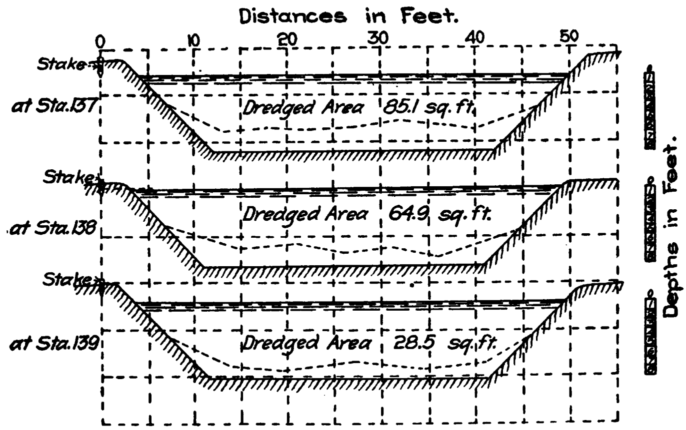

Fig. 57. Cross Sections of Canal.

dotted line and the lower full line for each station, represent respectively, the canal bottom, before and after dredging. The area included between the dotted line and the lower full line is the cross-sectional area of the dredged material. This area is determined for each station, either by calculation from the notes, or by counting the small squares included between the two designated lines on the cross-section plat, or by measuring the platted area with a planimeter. The areas of the several sections having been determined, the quantities are calculated, either by the method of average end areas or by use of the prismodial formula. In this instance the method of average end areas is applicable and the calculation is made as follows: The total cross-sectional areas, before dredging at stations 137, 138 and 139, are respectively: 224.5, 244.7 and 260.3 square feet. After dredging the cross-sectional areas at these re-

spective stations are 309.6, 309.6 and 308.8 square feet. By subtracting the smaller area at each station from the larger one for that station we get the dredged area. In this instance the dredged areas at the respective stations have the following values: Area at Station 137 = 85.1 square feet; area at Station 138 = 64.9 square feet; area at Station 139 = 28.5 square feet. Then, by method of average end areas, we get the following equations:

Volume of material between Sta. 137 and Sta. 138,

$$= \frac{85.1 + 64.9}{2} \times \frac{100}{27} = 277.^{8} \text{ cu. yds.}$$

Volume of material between Sta. 138 and Sta. 139,

$$= \frac{64.9 + 28.5}{2} \times \frac{100}{27} = 173.^{0} \text{ cu. yds.}$$

In some cases the measurement of material in place is conducted as follows: A suitable dumping place or place of deposit is selected and its dimensions and shape are carefully and accurately determined by soundings at suitable points. Its capacity is then calculated by mensuration. This dumping place is then filled to the required height with the dredged material, after which, soundings are again made to determine the dimensions and capacity of the space that has been filled in.

In many instances it is found that when dredged material is measured in place, according to the methods that have been described, full measurement will not be made except when conditions are favorable. The sides of the excavation will frequently cave or slip, except when the material excavated is rock or clay; and in many instances outside material will flow in and partially refill the excavation. In such cases soundings made within the required limits of excavation will not show the full amount of material removed. Recourse should then be had to other methods of measurement.

Scow Measurement.

A good way to determine the quantity of material dredged or excavated under water at a given locality, is to measure the material after it has been dredged and deposited on board a barge or scow; such a process is called "Scow Measurement."

Dredged material, after being deposited on a scow, may be measured by determining the dimensions of the load, or by the displacement of the scow. By the first method the scow is divided into compartments, whose respective capacities are known, and these compartments are filled or partially filled with the dredged material.

In this way the quantity of material is readily determined by measure. In the case of a deck scow the material is placed in convenient form for measurement and its dimensions are then ascertained, and its volume calculated.

When measurement is made by displacement the volume of water that is displaced by the barge is determined by first finding the respective depths to which the scow is immersed before and after loading. Then, knowing the dimensions of the scow and the respective weights of unit volumes of the water in which the scow floats, and of the material with which the scow is loaded, the load on the scow is determined by calculation.

When a scow is not loaded the average depth of its bottom below the water surface is called the depth of immension *light*. When it is loaded the average depth of its bottom below the water surface is called the depth of immersion *loaded*. The process of determining the depths of immersion on the sides of a scow is called gaging. When a scow is light, that is not loaded, the line of the water surface along its side is called the light waterline. When the scow is loaded the water line along its sides is called the load water line. Thus in Figure 58, in which is represented the longitudinal section

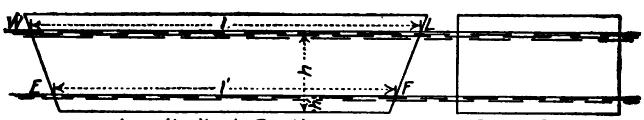

Fig. 58. Scow, Loaded and Light.

of a scow on the water, E-F is the position of the light water line; W-L is the position of the load water line, h′ is the depth of immersion light, and h is the depth of immersion loaded. In order to measure a load on a scow it is necessary to know its average depth of immersion, both light and loaded; also the respective lengths of the light water line and of the load water line.

The average depth of immersion is generally the average of ten gagings as follows: one at the center, two at the ends, and two midway between the center and the ends; this makes five gagings on a side or ten gagings in all. The depth of each gaging is noted; then, to the sum of the four end depths add twice the sum of the four intermediate depths and divide the total by 16. The result will be the average depth of immersion of the scow, either light or loaded, as the case may be. The average length of two measure-

ments, one on either side of the scow, is taken as the length of the water line.

The information obtained in the manner just explained can, for convenience, be expressed by formula as follows: For any given scow:

Let l' = length of light water line in feet;
Let l = length of load water in feet;
Let h' = depth of immersion light;
Let h = depth of immersion loaded;
Let b = width of scow in feet;
Let k = weight in pounds of a cubic foot of water;
Let w = weight in pounds of a cubic yard of the material to be measured;
Let x = the load of the scow.

Then, by formula: $$x = \frac{\frac{l + l'}{2} \times b \times (h - h^1)\,k}{W} \qquad (1)$$

For bodies of fresh water $k = 62.4$; for salt water $k = 64$.

Example 1. An empty scow floats in a river with a depth of immersion, $h' = 2$ feet; the length of the light water line $l' = 42$ feet. After being loaded with dredged material the depth of immersion loaded, h, = 8 feet, and the length of the load water line, l, = 48 feet. The width of the scow, b, = 20 feet, and the weight of the material per cubic yard = 2,750 pounds. Required the number of cubic yards of material composing the load. By substituting the given values in equation and using the value of k for fresh water, we have:

$$x = \frac{\frac{48 + 42}{2} \times 20 \times (8-2) \times 62.5}{2750} = 122.7 \text{ cu. yds.}$$

If, instead of the number of cubic yards, the weight of the load in tons is required, make $w = 2{,}000$ = number of pounds in a ton. Substituting this value in equation and reducing we have:

$$x = 168.75 \text{ tons.}$$

Example 2. A scow floating in a bay, was loaded with broken stone. The results of gagings, made before and after loading, were as follows:

$h' = 2.7$ feet; $h = 9.7$ feet; $l' = 62.7$ feet; $l = 69.5$ feet. The width, $b = 26$ feet; the weight of the broken stone = 2,650 pounds per cu. yd. Required the number of cubic yards of stone loaded

on the scow. By substituting the given values in equation and using the value of k for salt water, we have:

$$x = \frac{\frac{62.7 + 69.5}{2} \times 26 \times (9.7 - 2.7) \times 64}{2650} = 290.5 \text{ cu. yds.}$$

Survey to Determine Capacity of Lake.

It is frequently necessary to determine with more or less exactness the volume of water contained in a lake or a storage reservoir or any similar body of water of considerable size. In a case of this kind it is customary and proper to determine the required volume by means of a hydrographic survey. Such a survey should be made in accordance with such of the methods that have been described in this manual as are best suited to the case in hand. In making such determinations two general methods are used; these are called respectively "Method by Contours" and "Method by Cross-section," as in the case, previously described, of calculating the capacity of a proposed reservoir. The corresponding methods of determination for both cases are entirely similar in principle; the essential difference between them consists in the method of conducting the field work of the necessary surveys. In order to explain clearly the process of making a capacity survey of a lake or of a similar body of water, both methods of determination will be discussed. This will involve some repetition because of the similarity above referred to, of the methods used for computing volumes and capacities in the two cases.

Method by Contours.

When a close approximation of the volume of water contained in a lake or reservoir is required the method of determination by contours will generally afford the most nearly exact results. When this method is used an outline survey of the lake is first made; then, by means of soundings, depths at a sufficient number of points are found to designate a series of contours of the submerged area. The contour interval, or the vertical distance between adjacent contours, is fixed according to the slope of the ground and the degree of exactness required in the work. The notes thus obtained are platted and a map is made, showing the outline of the water surface and the positions of the several contour lines. The surface of the water and the successive contours will lie in a series of parallel planes. The figure included between any two adjacent planes will resemble a prismoid, whose end areas are those enclosed within the corresponding contour lines, and whose height is the contour interval.

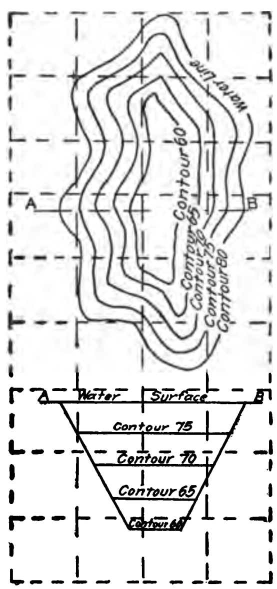

Fig. 59. Plan and Section of Lake.

The area of the water surface and the areas enclosed by the several contour lines are calculated separately and tabulated. These areas may be calculated directly from the map by dividing them into triangles and computing the area of each triangle, and then taking the aggregate of the partial areas in each figure for the area of the entire figure. If the outline is very irregular, calculation with the aid of a planimeter will usually be the quickest and most convenient method to use. Having computed the areas of the several planes, and knowing the contour interval, the next step is to calculate the volume of water in the lake. This may be done, either by the method of average end areas, or by the use of the prismoidal formula. In a case where the difference in area between successive contours is large the average end area method will give incorrect results and, on that account, should not be used. In most cases the use of the prismoidal formula will afford satisfactory results and it is generally used in calculating volumes of such figures as are under consideration.

For the sake of convenience the two methods will be expressed by formula. In Figure 59, in which is shown the outline and several contours of a lake, also a cross-section, the several factors may be expressed by symbols as follows:

Let a, b and c be the respective areas enclosed by three successive contours; h = the contour interval; v = the volume of a given prismoid; v′ = the volume of the adjacent prismoid.

Then by average end areas:

$$v = h\left(\frac{a+b}{2}\right);\ v^1 = h\left(\frac{b+c}{2}\right)\ \therefore\ v + v^1 = h\left(\frac{a}{2} + b + \frac{c}{2}\right). \qquad (1)$$

When the prismoidal formula is used two prismoids are taken as one, in which case the intermediate area is the middle area and

the height of the prismoid so taken is twice the contour interval.

In this case, using the same symbols as above, the formula for volume is

$$v + v^1 = \frac{2h}{6}(a + 4b + c) \qquad (2)$$

In some instances it will be found that a lake or reservoir basin contains an odd number of prismoids, and when the prismoidal formula is used, there will be a prismoid for which there is no known middle area. In a case of this kind the odd prismoid, which is usually at the bottom, may be calculated by average end areas without causing much error. If the prismoidal formula is used, a middle area must be interpolated; when this is done the process is the same as that explained for calculating the capacity of a reservoir.

METHOD BY CROSS-SECTION.

When it is required to determine with only a fair degree of approximation, the volume of water in a lake, and it is not desired to incur much expense or to devote much time to the work, the method by cross-section will usually be found both practical and effective.

When this method is used, the outline of the water surface is first determined by survey, using such method as is most suitable for the case in hand. The notes are then platted and an outline map is made of the water surface, showing such topography as is required. The next step is to divide the area covered into a series of trapezoids by parallel lines, extending entirely across the area from side to side. These lines are projected on the map by selecting points on the outline for extremities of the parallel lines in such a manner as to form the best conditioned figures. These lines are then located in the field and constitute a series of sounding ranges; at each range, by means of soundings, a profile of the lake basin is made and the cross-sectional area of the lake is determined for that range. This will divide the lake basin into a series of figures resembling prismoids, whose bases are the cross-sectional areas, and whose altitudes are the perpendicular distances between adjacent ranges. The volume of water contained in the lake is determined by calculating independently the volume of each prismoid and adding together the partial volumes thus found to obtain the total contents of the lake.. Such calculation may be made by the method of average end areas or, if more exact results are wanted, the prismoidal formula is used.

In order to illustrate this method of determining volumes an example will be given, showing its application in the case of a small lake. A plat of a lake is represented in Figure 60, in which the outline of the water is shown by the irregular line; the series of

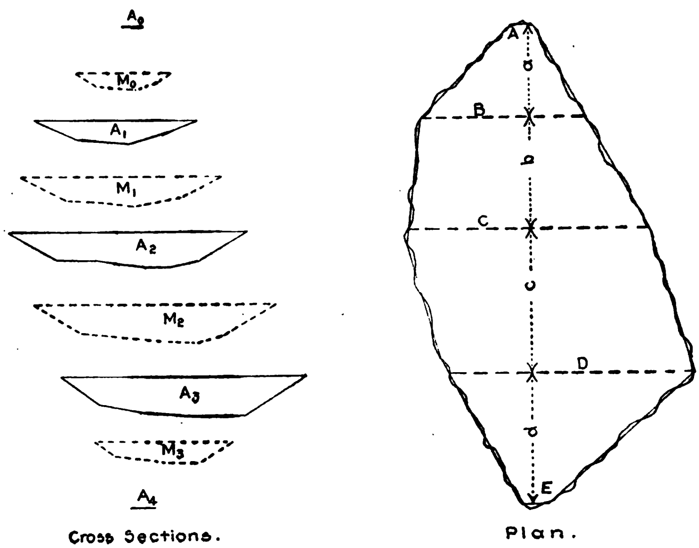

Fig. 60. Plat of Lake, showing Parallel Sections.

straight, full lines, near the water line, represent the several courses of the survey, which in this case is a closed traverse. The dotted horizontal lines are parallel sounding ranges, and the vertical dotted lines show the perpendicular distances between ranges.

Let A_0, A_1, A_2, A_3, and A_4 = the areas of cross-sections at A, B, C, D and E respectively;

a, b, c and d = perpendicular distances between the ranges A, B, C, D and E respectively;

v_0, v_1, v_2 and v_3 = volumes of prismoids whose altitudes are a, b, c and d respectively;

V = total volume of water in lake $= v_0 + v_1 + v_2 + v_3$.

The ends, A and E, of the figure representing the lake, are simply straight lines, and the figure included between A and the cross-section on B is a wedge; similarly, the figure included between E and the cross-section on D is a wedge. In computing the volumes

of the end figures each wedge is calculated as a prismoid, one of whose end areas is zero.

In computing the total volume of water in the lake by the method of average end areas, using the symbols that have been given, we have the following equations:

$$v_0 = \frac{A_0 + A_1}{2} \times a;$$

$$v_1 = \frac{A_1 + A_2}{2} \times b;$$

$$v_2 = \frac{A_2 + A_3}{2} \times c;$$

$$v_3 = \frac{A_3 + A_4}{2} \times d;$$

$$\text{and } V = \tfrac{1}{2}\left[(A_0 + A_1)\,a + (A_1 + A_2)\,b + (A_2 + A_3)\,c + (A_3 + A_4)\,d\right] \qquad (3)$$

When the prismoidal formula is used for computing volumes, it is good practice to find the middle areas by interpolating a mean cross-section between the two end cross-sections of each prismoid. This is done for a given prismoid by platting together on cross-section paper its two end cross-sections and determining the mean section graphically. This method is illustrated in Figure 61, in which A B C and D E F represent respectively the cross-sections made on ranges B and C in Figure 60. The dotted cross-section,

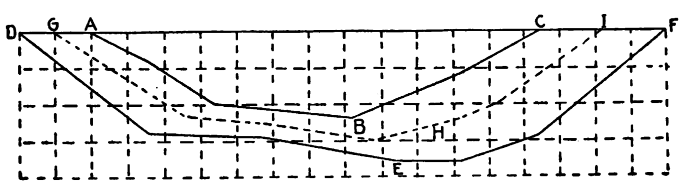

Fig. 61. Method of Interpolating Middle Area.

G H I, which is interpolated midway between the two sections first drawn, is the middle area of the prismoid whose end areas are the two measured cross-sections. The middle area of each prismoid is determined in a similar manner. In the example under consideration the measured cross-sections are shown in full lines, while those that are interpolated are shown in dotted lines in Figure 60. These interpolated cross-sections are designated respectively by the symbols m_0, m_1, m_2, m_3. Then, using the same symbols to designate

values as before, the equations for the respective volumes, by the prismoidal formula, are as follows:

$$v_0 = \frac{a}{6}(A_0 + 4m_0 + A_1);$$

$$v_1 = \frac{b}{6}(A_1 + 4m_1 + A_2);$$

$$v_2 = \frac{c}{6}(A_2 + 4m_2 + A_3);$$

$$v_3 = \frac{d}{6}(A_3 + 4m_3 + A_4);$$

and $V = \frac{1}{6}[(A_0 + 4m_0 + A_1)a + (A_1 + 4m_1 + A_2)b + (A_2 + 4m_2 + A_3)c + (A_3 + 4m_3 + A_4)d]$ (4)

Example. In order to give a practical illustration of the application of the two methods of computation that have been explained, the areas of the measured sections shown in Figure 60 have been calculated; these will be used in the formulas for volume and the results will be shown.

The areas are given in square feet as follows:
A_0 = O, A_1 = 2280. A_2 = 5950, A_3 = 6685, A_4 = O.; a = 175 ft. b = 210 ft., c = 270 ft., d = 245 ft.

Then, by mean end areas, these values are substituted in formula (3), which becomes
V = ½ (399,000 + 1,728,300 + 3,411,450 + 1,637,825) = 3,588,288 cubic feet.

In using the prismoidal formula, the interpolated middle areas are required; these are given in square feet as follows:

m_0 = 720, m_1 = 3,705, m_2 = 6,210, m_3 = 1,860.

Substituting known values, in equation (4), we have:
V = 1/6 (903,000 + 4,840,500 + 10,118,250 + 3,460,625) = 3,220,396 cubic feet.

PART II.

MEASUREMENT OF STREAM FLOW.

Introduction.

An important department of hydrographic surveying is that concerned with observations and measurements for the purpose of determining the discharge of streams.

The great increase in the utilization of water power in recent years, due to the efficiency of modern methods of power transmission by electricity, has directed public attention to the value of rivers and streams of considerable size as a source of power.

The value, for irrigation purposes, of water obtained from streams has been demonstrated by its use in the reclamation of vast areas of arid land. This is especially true in the western part of the United States, where the general Government is conducting on a large scale a series of reclamation projects, involving the use of many streams for irrigation.

A third important use to which rivers are subjected is as a source of water supply to cities and towns. As the population increases and cities grow larger, the question of water supply increases in importance, and streams of sufficient size for such a purpose become more and more valuable.

In view of these facts, the measurement of stream flow or, as it is sometimes called, the gaging of streams, is a matter of common interest. In most cases where a stream is to be gaged, it is important that the work be correctly done, especially where the stream is to be utilized for some specific purpose, such as has been stated.

In most cases, where it is necessary to gage a stream, it is important that the discharge be correctly determined, not only at ordinary stages of water, but at periods of maximum and minimum flow. The latter should be especially considered, since the minimum flow of a stream marks its limits as a source of supply. Many costly mistakes have been made by basing calculations and estimates upon discharge measurements that were made in a stream at ordinary low water stage, instead of at extreme low water stage in the stream measured. Such considerations, however, are largely a matter of judgment rather than of detail and are not, strictly speaking, within

the scope of this manual. The various methods of making discharge measurements, that are in common use, will be discussed; these methods are applicable for any stage of water in a given stream.

In making measurements of stream flow it is of course desirable that rapid and economical methods be used when such methods are of sufficient accuracy. There are in common use a number of methods of measuring the flow of streams. In general these may be classed under two heads, as follows: 1. By determining the mean velocity and the cross-sectional area of a stream for a given location; 2. by means of weirs. The latter method is only applicable in special cases and under favorable conditions; it will be discussed and described in detail later.

In using the several methods included under the first head the two factors to be considered are those that have been mentioned, viz: the cross-sectional area of the stream, and the mean velocity of the current. The units commonly employed are those expressing the area of cross-section in square feet, and the mean velocity of current in that cross-section in feet per second.

The cross-sectional area is computed from the soundings made at frequent intervals across the channel of the stream. These intervals should be so selected that the bottom of the stream may be considered a straight line between adjacent soundings.

The current velocity is usually determined in sections of the stream channel, such sections extending between the positions of adjacent soundings; the summation of the areas of the several sections gives the total area of cross-section. When the total flow of the stream at some given point or station is known, and this flow or discharge is divided by the cross-sectional area of the channel at the station, the result is called the mean velocity of the stream at the point in question. In most methods of stream measurement it is the mean velocity that is sought to be determined; it cannot be determined definitely, however, until the total flow is known. For determining the mean velocity of the current in a stream, there are a number of methods, giving results more or less accurate. All of these should be familiar to the hydrographic surveyor, in order that the method best suited to the conditions at hand may be applied.

Discharge Station.

When it is required to determine the discharge of a given stream by a method in which the area of cross-section and the mean velocity are factors, a suitable place should be selected at which to make the necessary measurements and observations; such a place is called a

discharge station. In locating a discharge station a straight, regular reach of the stream should be selected, in which the channel is free from obstructions and the cross-sections are fairly uniform in size and shape. The channel should preferably be straight for some distance above and below the discharge station, in order that the flow of water may be uninfluenced by changes in its direction either on entering or leaving the discharge station.

Gage. When a suitable location has been found a water gage is established, on which the height of the water can be easily read to tenths of a foot. The gage may be either vertical or inclined; it should be made and graduated according to the manner that has been described for water gages. The zero of the gage is referred to a permanent bench mark. The datum used is immaterial, provided the zero of the gage is set low enough to be covered by water even at the lowest stage. Such a precaution is necessary in order to obviate the use of minus readings.

VELOCITY MEASUREMENTS.

Two general methods are employed to determine the current velocity of a stream. These methods are: 1. by means of floats; 2. by the use of a current meter. Other methods for determining current velocities are used by hydraulicians, the most common of such methods being the Pitot Tube. These latter methods, however, are not well adapted for use in ordinary hydrographic survey work and will not be discussed here.

When either of the two methods that have been enumerated is used, the selection of a discharge station, as above described, is necessary, and the description given may be considered applicable to either or both of the two general methods of determination of velocity. Each method, however, differs materially from the other in details; they will be described in order.

FLOATS.

Current velocities are frequently determined by the use of floats. Of these there are three general types in common use, viz: 1. Surface floats; 2. Immersed or double floats; 3. Rod or tube floats. Whichever form of float is used the general method of procedure is practically the same in each case.

Base Line. In arranging a discharge station for float measurements a base line should be carefully laid off on the bank, as close as convenient to the water and as nearly as possible parallel to the axis of the stream. The course or path of the floats should be from

100 to 300 feet in length; at distances 100 feet apart on the base, and at right angles thereto, two lines, constituting sounding ranges, are laid off, extending across the stream. Such an arrangement is illustrated in Figure 62, which represents a discharge station on a river. In this figure A-B is a base 100 feet long and A-C and B-D are the upper and lower ranges respectively. This arrangement is suitable for a base not more than 100 feet long; for a longer base line, additional sounding ranges, spaced at equal intervals apart, should be laid off.

Cross Sections. The base line and the ranges having been laid off, soundings are made, and the cross-section of the stream at each range is determined. If the stream is not too wide the soundings are spaced on a graduated wire or rope, in the manner previously described. If the depth of water does not exceed about four feet, the soundings can be made by wading, the depths being read on a graduated rod to feet and tenths. In case wading is impossible, on account of the depth of the channel or the temperature of the water, a boat should be used in making the soundings.

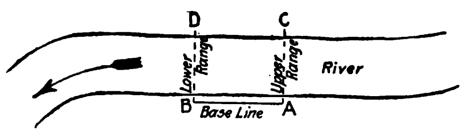

Fig. 62. Discharge Station.

On large rivers, where a graduated rope cannot be utilized, the positions of the several soundings should be located by angular measurement or by stadia, both of which methods of location have been described. Where a series of measurements are to be made at successive periods on the same sections, the soundings may be located by the intersection of fixed ranges, in the manner that has been described.

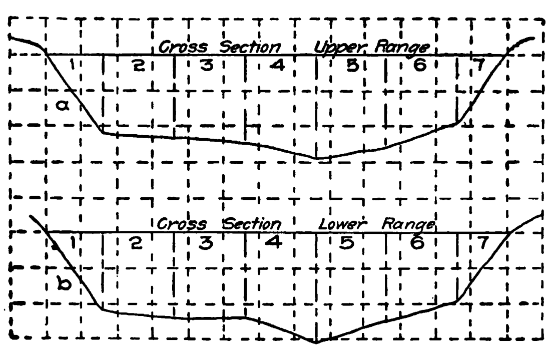

Fig. 63. Cross Section at Discharge Station.

The soundings having been made at suitable intervals, the cross-section of the channel at each range is divided into a series of trapezoids, whose parallel sides are the depths of adjacent soundings, and whose altitudes are

the distances between the respective soundings. In each cross-section, in addition to the trapezoids that have been mentioned, the two end figures nearest the bank on either side, may be considered as triangles. Such arrangements are illustrated at *a* and *b*, Figure 63, which represent respectively the platted cross-sections on the ranges A-C and B-D, shown in Figure 62.

SURFACE FLOATS.

In a case where exact results are not required, or where facilities for observation are limited, velocities may be determined by the use of surface floats. These may consist of small wooden chips, or small disks of some light material, that will float on the surface and will not be affected injuriously by water. They should be so constructed as to float nearly flush with the surface so as to be but little affected by the wind. In making observations the floats should be placed in the water a considerable distance above the upper range, in order to acquire the full effect of the current before passing the range. On a narrow stream the ranges are marked with graduated ropes in the manner previously described. The floats should be started successively at different distances from shore, in order to determine the current velocity in different parts of the channel. The observer notes the time of the passage of each float between the upper and lower ranges, preferably by a stop watch, and also notes the position of each float with respect to the graduations on the ropes. In this way those portions of the stream that are covered by the paths of different floats can be noted, and the computations thereby simplified. The observations should be continued until all parts of the channel have been covered.

On wide rivers, where the ranges are designated by range poles on the banks, the location of each float, as it crosses a range, can be determined accurately by instrumental observation. For this purpose the instrument should be set up over some known point on the base line, preferably a sounding range, and clamped with its vernier at zero when the telescope is sighted along the base line, or along the range upon which the instrument is located. The upper plate is then unclamped and the telescope is turned in azimuth, with the line of sight following the float. At the instant the float crosses the upper range the observer is notified by signal from an assistant; he immediately ceases to turn the telescope, notes the time by his watch, which is lying open and face up on the upper plate of his instrument, also the angle on the vernier, and records the information in his note book. This operation is repeated as the float

crosses the lower range. The instrument used for reading the angles should preferably be a transit, although a plane table may be used with equally good results.

Ordinarily the results obtained by the use of surface floats are not of sufficient importance to justify the use of instruments for observing the positions or paths of such floats on the water. Since the observed velocities when using surface floats, are only rough approximations of the mean velocities of the filaments or vertical sections over which they float, it is an unnecessary refinement to observe their movements with great accuracy.

A good way to observe surface float velocities, and one that is sufficiently accurate for ordinary work, is as follows: The floats are launched by an assistant, from a boat or wading, at some distance above the upper range. The observer with a stop watch, notes the time exactly that a float passes the upper range; he then proceeds quickly to the lower range and notes the exact time the float passes that range; this operation is repeated for each float that is launched. Much time will be saved if an assistant is stationed on one range to signal the passage of floats to the observer, who is at the other range.

Surface floats show approximately the surface velocity of the stream at the place of measurement. The results obtained by this method of velocity determination are subject to errors due to wind and to surface currents and eddies. The observed velocity is that of the water surface, while that required for calculating the discharge is the mean velocity of the entire cross-section. The relation of the surface velocity to the mean velocity of the filament or vertical section is not constant, but for streams of the same general character of bed, banks, velocity, etc., the ratio is sufficiently constant to be computed with fairly good results from surface velocity observations.

From the results of a large number of experiments and observations, the coefficients obtained for converting observed surface velocity into mean velocity, are as follows: For ordinary streams, discharging not more than 100 cubic feet per second, on stony beds, 0.8 of the mean surface velocity of the cross-section will represent the mean velocity for that section. In general it may be stated that the coefficient is comprised within the limits of 0.8 and 0.9, depending upon the size of the channel and the nature of the bed. The coefficient would be greatest for large, deep rivers with smooth, uniform channels, and least for small, shallow streams with rough beds.

Where only a rough approximation of current velocity is wanted a single float, passing along the axis or place of greatest velocity of a stream, may be used. In such a case the mean velocity of the whole stream may be taken as equal to 0.8 of the velocity of the float.

The variation in the value of the coefficient to be applied to surface velocity in order to obtain the mean velocity, renders this method of measurement unsuitable for use in cases where accurate results are required. As a quick and convenient means of determination it may often be used with satisfactory results. In some cases, as at the time of high floods, or in swift rapids, when it is impossible to use other means, the results obtained by this method are often of considerable value.

DOUBLE FLOATS.

A double float consists of a small surface float connected by a fine wire or cord to a larger immersed float, which is so arranged that it will remain at approximately the point of mean velocity of the current. The surface float may consist of a flat block of wood, or of a watertight tin vessel or drum, which floats upon the surface of the water with sufficient buoyancy to prevent the lower float from sinking; it should be of such form as to offer a minimum surface to the wind. The sub-surface float may consist of two sheets of galvanized iron, fastened perpendicular to each other, forming in plan a cross; a weight may be attached to the lower part of the float to assist in keeping it in a vertical position in the water. A good form of sub-surface float consists of a tin or sheet iron cylinder, open at the top and bottom; this is weighted at the bottom with a circular rim of lead. The two floats are connected by a cord, preferably of silk or linen, and as fine as possible, consistent with the requisite strength. The tension on the connecting cord should be about two or three pounds, or sufficient to maintain the surface float as nearly as practicable in a vertical line above the lower float. A small flag should be attached to the surface float in order that its position may be easily determined at all times. In Figure 64 is

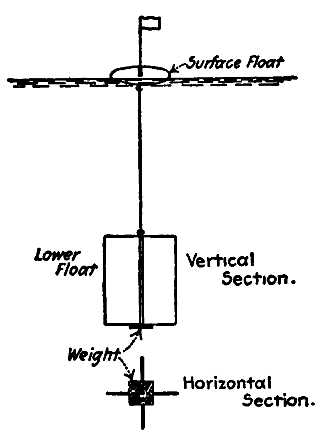

Fig. 64. Double Float.

illustrated a form of double float that has been used by the United States Engineers in current observations in the Mississippi River. The surface float is an air-tight buoy of galvanized iron, circular in plan and elliptical in cross-section, its major axis being about 10 inches and its minor axis about 5 inches. The sub-surface float consists of two sheets of galvanized iron, each 12 inches by 15 inches, fastened at right angles as shown. The flagstaff, consisting of a small wooden stick, fits into a tubular tin socket 3/8 of an inch in diameter.

The principal objection to the use of double floats in current observations is the uncertainty as to whether the cord is vertical and the consequent uncertainty as to the position of the submerged float. Another objection is the modifying effect of the surface float and the cord upon the velocity of the lower float. It is probable that in all cases the velocity of the lower float is affected to some extent by that of the upper one, as well as by the friction of the cord. At a great depth the exposed surface of the cord may exceed that of the float. A third objection is the uncertainty as to the vertical position of the lower float since, owing to changes in depth of the water and to local conditions, the point of mean velocity may change, while the length of the connecting cord must remain constant in each run. This last objection, however, should not prove serious if the discharge station has been selected with proper care, so as to insure approximate uniformity of depth throughout its length.

Locating Positions of Floats. Since double floats are used for determining velocities in streams of considerable size, it is generally advisable to locate their exact positions when crossing the upper and lower ranges of a discharge station. This may be done by instrument observation in the following manner: Two observers, each with a transit, are stationed, one at the upper and the other at the lower range. Each observer has his instrument set at zero on the other instrument; the observer on the upper range has the upper plate of his instrument unclamped, with the telescope directed along the range. The observer on the lower range, with the upper plate of his instrument unclamped, follows with his telescope the movement of the float under observation. The floats are launched at intervals, at some distance above the upper range, and at the instant a float crosses that range, the observer stationed thereon signals to the other observer, and, at the same instant, starts a stop watch with which he should be provided; he then directs his telescope toward the float and follows it with the line of sight. On re-

ceiving the signal the observer on the lower range, whose telescope has been following the float, arrests its motion and notes the angle between the line of sight and the base line. As a check on the reading of the stop watch he notes the time by his watch. He then directs his telescope along his range. At the instant the float crosses his range he makes a signal to the other observer and also notes the time by his watch. The observer on the upper range, when he receives the signal, arrests the motion of his telescope, at the same instant stopping his stop watch; he then notes the interval of time that was required for the float to pass from the upper to the lower range, and the angle made by the line of sight with the base line. This operation is repeated with other floats until a sufficient number of observations have been made.

In Figure 65 let A-C and B-D represent the upper and lower ranges respectively of a discharge station, and F and F_1 the respective positions of a given float in crossing them. The position F is located by the intersection of the line of sight B-F with the range A-C. Similarly the position F_1 is located by the intersection of the line of sight A-F with the range B-D. As each observer notes the passage of the float across the range upon which he is stationed, he notifies the observer on the other range by a prearranged signal. In some cases a wire circuit is laid connecting the two stations, and signals are given with a telegraph sounder. Ordinarily, however, signals may be given by shouting, or preferably by calling through a megaphone. The path of the float between the two ranges will usually be a curved line, somewhat longer than the perpendicular distance between the two ranges. This will not affect the computation, however, since the path taken by the float is considered that of the vertical filament in which the float moves; the object of the measurement is to determine the mean velocity of discharge rather than the actual velocity of some particular filament or vertical section of the water. The velocity of each float is obtained by dividing the distance in feet between the upper and lower ranges by the number of seconds required to pass from one range to the other.

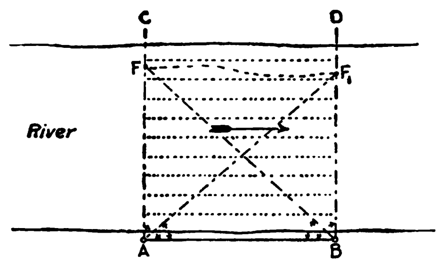

Fig 65. Method of Observing Path of Float.

Tube or Rod Floats.

Tube or rod floats consist of hollow tin cylinders or wooden rods of uniform size, usually from 2 to 3 inches in diameter. They may be of adjustable length and weighted at the bottom, so that they will float vertically, with only 2 or 3 inches of their length exposed above the surface of the water, as illustrated in Figure 66. When hollow tubes are used they may be weighted by filling the lower part with sand or shot until the tube floats at the required depth.

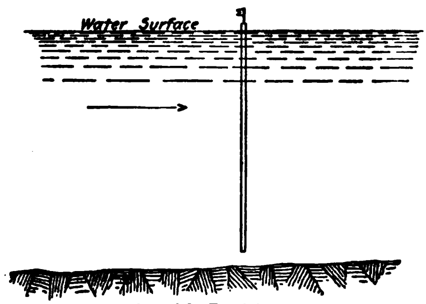

Fig. 66. Rod Float.

The velocity of a rod float is theoretically the same as the mean velocity of the filament or section in which it moves. The closeness of the results will depend largely upon the amount of clearance between the foot of the float and the bottom of the stream; this clearance should be as small as possible without causing the lower ends of the floats to scrape upon rocks or other obstructions at the bottom, thus retarding their movements. If the floats have much clearance they will not be affected by the films of least velocity nearest the bottom, and the velocity shown will be too great.

It was stated by Mr. J. B. Francis, as the results of experiments made by him, that rod floats travel a little faster than the mean velocity of the water, even for the depth of immersion. On the other hand, Col. Cunningham, another good authority, as a result of his experiments, states that such floats move somewhat slower than the water in which they are immersed.

For ordinary stream measurements, however, when rod floats of suitable length are used, it is sufficiently exact to call the observed velocity of the float the mean velocity of the section or filament in which it moves.

The positions of rod floats in crossing upper and lower ranges may be determined by the same methods as those that have been described as being suitable for surface and double floats.

Rod or tube floats are free from many of the objections applicable to double floats, since there is no uncertainty as to their position, nor as to the point of mean velocity in the channel. They are, however, not suitable for very deep rivers, or for channels where the depth varies considerably, or where weeds grow in the bed of the stream.

THE CURRENT METER.

The current meter is an instrument for determining the velocity of flow of streams. It is the most convenient and satisfactory device in use for ascertaining current velocities, and has been found best adapted for general use in stream measurements.

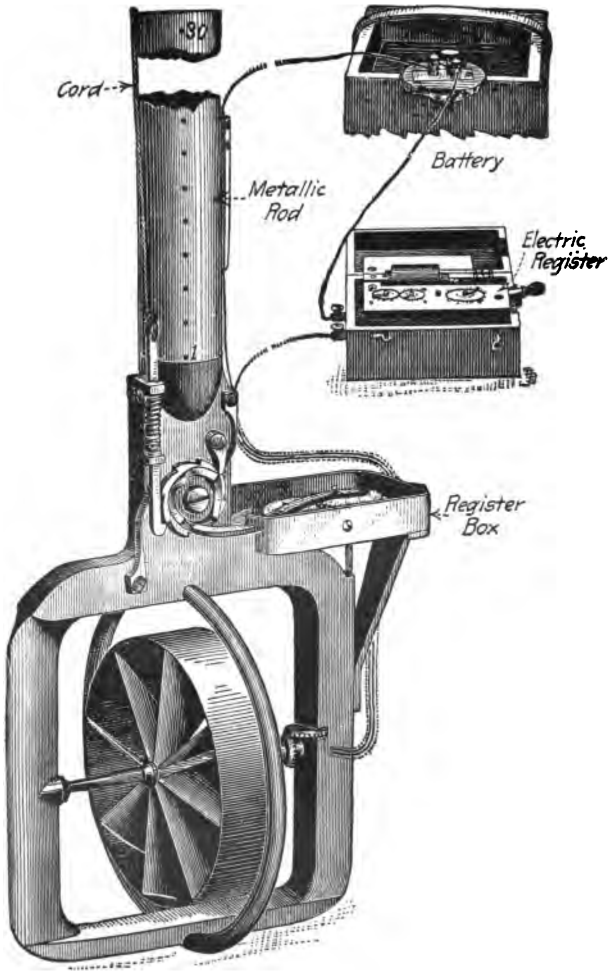

Fig. 67. Fteley Current Meter.

There are manufactured and in common use several different types of current meter. Of these the author is familiar with two; the Fteley meter and the Price meter; these will be described.

The Fteley Meter. In Figure 67 is given an illustration of a Fteley current meter. As there shown the instrument consists of a wheel with helical vanes, mounted on a horizontal axis or spindle, and connected by beveled gearing with a register or counter, which indicates on a dial the number of revolutions of the wheel. The registering mechanism can be thrown in or out of gear by pulling an attached cord. The dial wheels are protected from floating particles of detritus by being encased in a box with a glass cover. For observations where it is not convenient to draw the meter out of the water or to the surface for reading the register, an electric register is used. This is connected with the beveled gearing by an insulated wire as shown; it can be kept close to the observer in a boat or on land as most convenient.

The meter is attached to a metallic rod, which is graduated to feet and tenths, the zero of the graduations being at the bottom of the meter frame.

When in use the meter must be held in the water with the wheel facing the current which causes it to rotate. The handle must be maintained in a vertical position and the face of the wheel must be perpendicular to the stream lines so as to obtain the full force of the current. When the instrument is in position and in readiness for a measurement, the observer, after noting the reading on the dial of the register, warns his assistant, who should be provided with a stop watch, that he is ready. At the instant the observer pulls the string that releases the revolving mechanism, he calls out "start" to the assistant, who immediately starts his stop watch. When the observation is ended he calls out "stop" to the assistant, who immediately stops the watch and then notes the exact period of time that has elapsed, also the number of revolutions of the wheel, as shown by the dial. In the author's practice he has found that the best way to obtain simultaneous action of both observer and assistant in the matter of starting and stopping the meter and the stop watch, is for the assistant to closely watch the motion of the observer's hand holding the cord, starting and stopping his watch at the instant the cord is pulled.

The Fteley meter, as described, is well adapted for work in small, shallow streams, on account of its lightness, simplicity and ease of handling. The author has made extensive use of this type of meter, with satisfactory results, in small streams that were not too deep for wading. On account of its form this meter can be held very close to the bottom of a stream, thus obtaining velocities at points not fully accessible for other types of meters. It is, how-

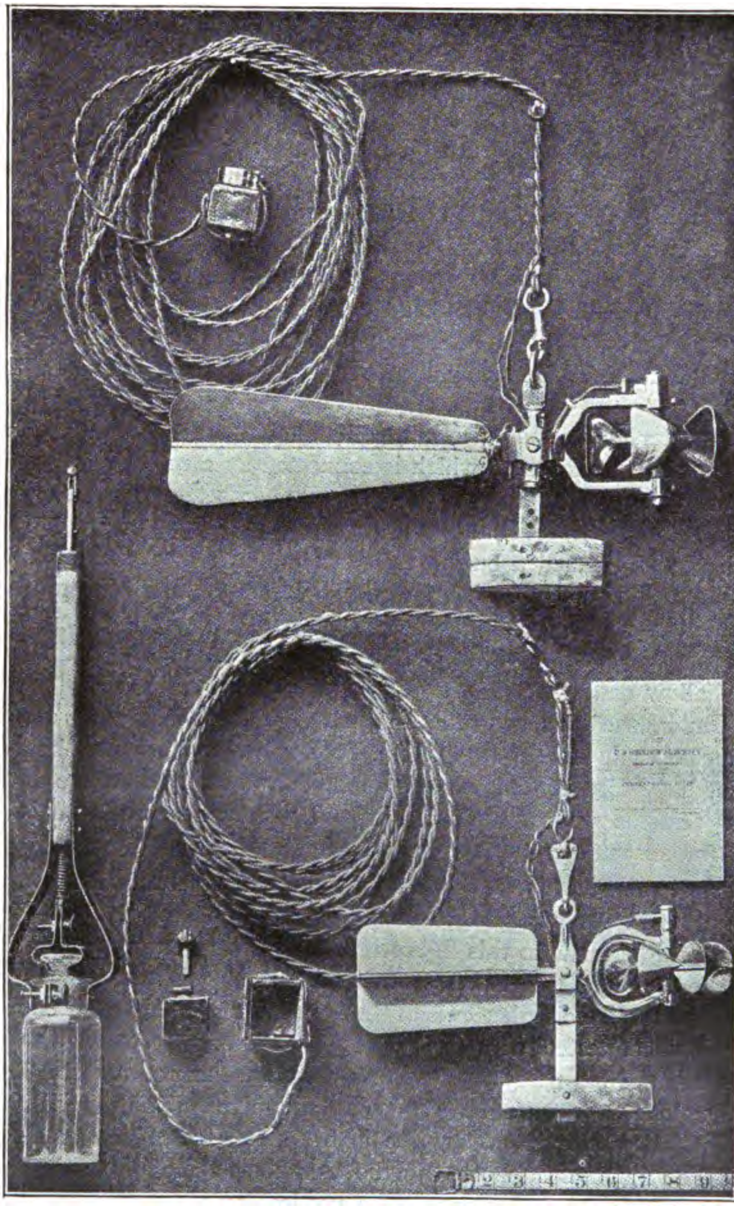

Fig. 68. Price Electric Current Meter, with Buzzers.

ever, not well adapted for observations in deep water, especially where the current is of appreciable force. In such cases the **Price** meter is an excellent type of instrument to use.

The Price Current Meter. This is a different type of meter from that just described, as will be seen by observing Figure 68, in which is shown a photograph of two Price meters with their equipment. Two forms of this meter are made. One form is provided with an electric registering apparatus, similar to that described for the Fteley meter. The other form has an arrangement by which the revolutions of the meter wheel can be detected by sound; this form is called an acoustic meter.

The Price acoustic meter is extensively used in the hydrographic observations of the United States Geological Survey. The following description, together with accompanying illustrations, have been abstracted from Water Supply and Irrigation Papers issued by the Survey.

The meter consists of a wheel, containing five conical cups, rotating about a vertical axis, which is connected by a copper wire cable to a small battery buzzer, and is so arranged as to make and break contact with each revolution of the wheel; this is indicated by a peculiar sound called a buzz. In Figure 68 is shown two sizes of Price acoustic meter as used by the Division of Hydrography of the United States Geological Survey. The manufacturers now make only one size of this meter which is adapted for both deep and shallow water.

When in use in deep water the meter is suspended by a double conductor cable of No. 14 or No. 16 flexible copper wire, heavily insulated. Wire of that size is of sufficient strength to hold the meter and the weights, and it obviates the necessity of additional rope for suspending the equipment.

Construction of Meter. In Figure 69 is shown a cross-section of a small Price current meter, showing details of construction. Reference will be made to this figure in the following explanation. The cable for holding the meter is attached thereto with a spring snap hooked into the circular end of the trunnion. The heavy copper wires are connected with the two meter binding posts by smaller and more flexible wires; one wire is threaded through a metal loop on the yoke as shown. These wires should be flexible and loose to allow the meter to swing free in the metal frame when it is in use. The meter is supported in the trunnion as shown, and is free to swing in a vertical plane. The vertical axis or cup shaft terminates at the lower end in an inverted cone, which bears or turns on a cone-shaped point called the point bearing. This is the most delicate part of the meter and should be given the greatest care, since it is made of highly tempered steel and is liable to be fractured or

broken. In order to protect the point bearing during shipping or carrying the meter, a milled sleeve is provided, which is threaded on the inside and screws up or down on the plug at the extension of the lower end of the cup shaft. After the meter has been used, and before placing it in the wooden case, the milled sleeve should be screwed down until it bears on the top of the plug and raises the cups and cup shaft clear of the point bearing, thus protecting it from possible injury. When preparing to make a measurement with the meter the milled sleeve should be screwed up on the cup shaft as far as it will go, so as to be absolutely certain that the cups are turning on the point bearing, and are working with the least possible friction. This sleeve is milled for adjustment with the fingers and not with a wrench or pliers.

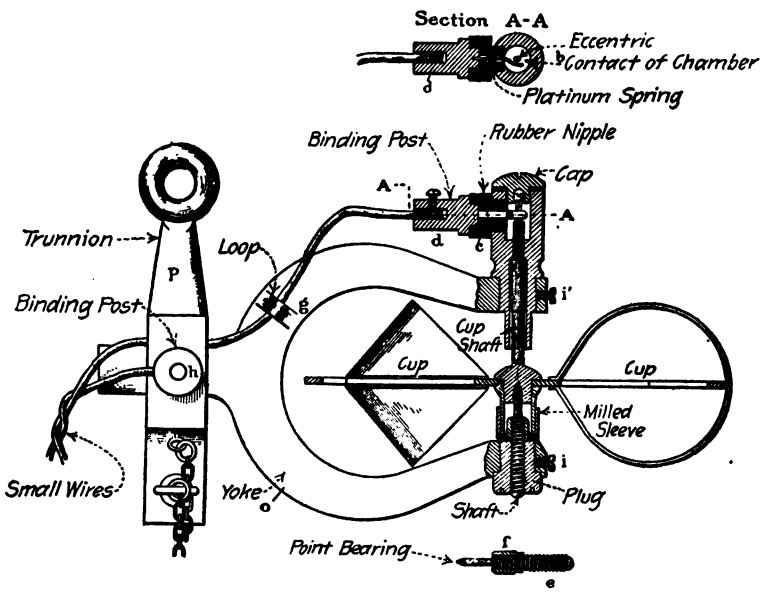

Fig. 69. Cross Sections of Small Price Electric Current Meter, showing Details.

Section A-A, Figure 69, shows the construction of the binding post and contact spring of the meter. A flexible, well-insulated copper wire (No. 20 or smaller) is drawn through the metal loop of the yoke; the end of the wire, free from insulation, is thrust into the metal binding post and secured by the small set screw. This metal binding post terminates in a slender platinum spring, which extends through the hard rubber nipple into the contact chamber. The upper end of the cup shaft terminates in the contact chamber

with an oval-shaped eccentric, which makes a contact with the spring at each revolution of the meter wheel. This contact can be prolonged or shortened by bending the point of the contact spring in the contact chamber in the desired direction. The oval-shaped eccentric end of the cup shaft is detachable and can be removed by taking off the cap, holding the cups firmly, and applying a screw driver to the small slotted head.

The insulating nipple is made of hard rubber, and is likely to break if the binding post receives a sharp blow. Before removing or replacing the binding post, the eccentric-shaped top of the cup shaft should be taken out. If this is neglected the contact spring will be destroyed by the turning of the binding post.

In charging the battery cell used with the electric buzzer, furnished with the current meter, one-half teaspoonful of bisulphate of mercury is sufficient. Fill the cell with water and insert the zinc pole with the rubber stopper attached. When putting the battery cell in the leather case, care must be taken to have the small platinum point on the lower end of the cell and the screw head of the rubber stopper make perfect contact with the copper plates. If the buzzer makes but a faint, clicking sound instead of a buzz, the metal cap covering the buzzer should be removed, and the small, upright brass point adjusted with a knife blade by bending until the armature produces the desired sound. The liquid should not be allowed to remain in the battery overnight, as it would generate gas and produce pressure sufficient to cause the cell to leak at the rubber stopper, and the solution escaping, would destroy the leather of the case and the brass parts of the buzzer.

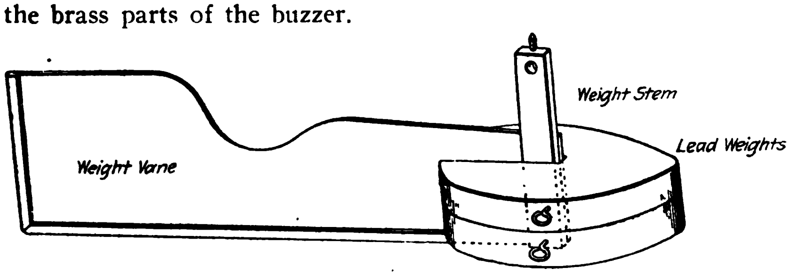

Fig. 70. Weights and Weight Vane of Small Price Electric Current Meter.

In Figure 70 there are shown the form of weights and weight vane that are used with this type of meter in deep streams for holding it in position. The lead weights are attached to the lower end of the trunnion by means of a detachable weight stem, to hold the meter steady in moving water; the higher the velocity of the current the greater the weight required to be used.

The weight vane should be attached to the weights at all times when the meter is suspended from a cable. When gaging small or shallow streams it may be necessary to make the observations by wading. Under such circumstances it will be more convenient to dispense with the lead weights and attach the meter to a light rod or pole.

When preparing to make discharge measurements the battery cell of the buzzer is charged, and the meter is taken from its case and attached to a pole, or to a cable with weight stem and weight vane, according to whether the observations are to be made in shallow or deep water.

After making a discharge measurement, or at the close of a day's work with the meter, the instrument should be carefully examined to detect possible injury, and freed from water, then carefully dried and packed in its case. The battery cell should be emptied, washed with water and packed up. The bearings of the cup shaft should be kept well oiled so that the cups will revolve freely and without friction.

This style of meter, in which the revolutions of the wheel are indicated by sound, is especially adapted for use in ordinary sized streams and in currents of moderate velocity. It is quite extensively used in the hydrographic work of the United States Geological Survey, for stream measurements and in irrigation investigations. Each revolution of the wheel is indicated by a buzz, the observer being required to count the number of "buzzes" in a given period of time, usually 50 seconds.

In cases where the current is quite swift, as at periods of high water, it is often quite difficult to count the revolutions of the meter, owing to the velocity of the current and the consequent rapidity of revolution. In such cases an electric register should be used to register the revolutions of the meter wheel. A good form of register is illustrated in Figure 71; this is actuated by a battery of three cells. The electric current is transmitted between the two poles of the battery through copper wires, which are attached to the meter in the same manner as shown in Figure 68. The electric register is enclosed in a brass case, showing three dials under a glass face. It has an electro-magnet which, when the circuit is made, moves a lever, at the end of which is a pawl carrying forward a ratchet wheel one tooth at every contact of the current. The large dial counts each revolution up to one

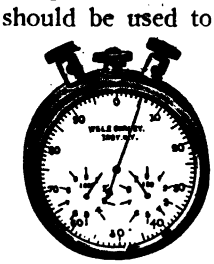

Fig. 71. Electric Register for counting the revolutions of the Meter Wheel.

hundred; the small dial on the right counts one thousand revolutions by each hundred, and the small dial on the left counts ten thousand revolutions by each thousand, as indicated by the graduations.

Use of Current Meter.

The current meter may be used to determine the mean velocity of a stream in four ways, as follows:

1. By making one measurement in a vertical section, at a depth corresponding to the approximate position of the filament of mean velocity.
2. By making observations at several points in a vertical and deducing the mean velocity therefrom.
3. By the integration method.
4. By point measurements, made at regular intervals throughout the cross-section.

These several methods will be discussed and explained.

Unit Measurements. Ordinarily when this method is used, the cross-section of the stream is divided into a convenient number of sections and a meter observation is made in each section, at a point that is estimated to be the point of mean velocity for the section. In making measurements of small rivers, it has been the custom of the hydrographic division of the United States Geological Survey to divide the cross-section of the stream into sections of regular width, say five or ten feet, and to determine the mean velocity in each section by holding the meter at a point six-tenths of the total depth of the section below the surface, and midway between the two sides of the section.

As the result of numerous experiments by hydraulicians it is considered that the point of mean velocity in a given vertical section is at a depth varying from six-tenths to two-thirds of the total depth of the section, measured from the surface down. The shape of the cross-section will usually exercise a considerable influence upon the location of the point of mean velocity. In the case of a wide, shallow stream, observations at six-tenths of the depth give fair values

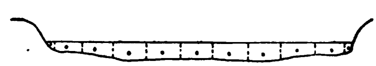

Fig. 72. Wide and Shallow Cross Section.

for mean velocity. In a canal or flume, or in a narrow and deep natural channel, the observations for mean velocity should be taken at about 0.67 of the depth. Thus, in Figure 72, which shows the cross-section of a wide shallow stream, the vertical dotted lines rep-

resent the boundaries of adjacent sections; the current observation for each section is taken on the vertical in the middle of the section, and at 0.6 of the distance from the top, as indicated by the small circles. In Figure 73 is shown the cross-section of a canal which is narrow and deep. In this case the observations are made in each section at 0.67 of the depth, as indicated by the small circles.

This method of determining mean velocities is adapted for use only in cases where extreme accuracy is not required, but where a rapid and fairly accurate method of stream measurement is wanted.

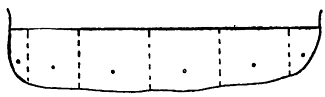

Fig.73. Narrow and Deep Cross Section.

It is a good method for general use. There are two variations of the method just described of unit measurements in a section. These are: a, observations at mid-depth, and b, observations at or near the surface.

Mid-depth Observations. In this method the meter is held in the center of each section and the observed velocity is multiplied by a coefficient to obtain the mean velocity. The coefficient commonly used is 0.95; this will vary, however, according to the depth of water and the nature of the bottom. As the result of many observations in the flow of rivers by different observers, it has been found that for large rivers with smooth beds, a coefficient of 0.98 may be required, while for small streams, with comparatively rough beds, a coefficient of 0.94 is applicable to mid-depth observations. In view of the variation in value of the coefficient it is somewhat better to measure the velocity at the point of mean velocity than to measure the velocity at mean depth and apply a coefficient.

Surface Observations. In many cases it is not practicable to make meter observations of velocity in a stream except at or near the surface. This is true where the velocity is very great, as in the case of rapids, or during the flood stage of a stream, when it is impossible to lower the current meter properly in the water or to maintain its position at a desired depth. In such cases it is customary to measure the surface velocity and to deduce the mean velocity therefrom by applying a coefficient. In the case of ordinary streams, with depths of from one to five feet, it will generally be sufficiently accurate to take 0.9 of the surface velocity, or of the velocity indicated by the current meter just below the surface, to represent the mean velocity of the section.

Multiple Measurements.

When observations are made at several points, properly spaced, in a vertical the mean of these observations will give, approximately, the mean velocity of the section in which they are made. The result will be more or less exact according to the number of observations made. Usually it will be sufficiently exact to make these observations in each vertical: at the top, middle and bottom respectively. The mean of the three velocities will be the mean velocity of the section. This practice, however, is not recommended when close results are wanted.

Method by Integration.

A rapid and effective method of determining the mean current velocity in a section is to move the meter uniformly in a vertical from top to bottom, then back to the surface; repeating the operation as often as desired. In this way the velocities are integrated mechanically, and the mean velocity can be computed by noting the time and the number of the up and down movements made.

Since the resulting velocity in a given section will be affected by the vertical motion of the meter, care should be taken that the motion be uniform and sufficiently slow to prevent the introduction of errors from this cause. As a result of experiments made by Mr. F. P. Stearns, it has been found that in moving a Fteley meter vertically at a velocity not exceeding 5 per cent. of the velocity of the current, no material errors are introduced.

The construction of the meter used should always be taken into account in considering or allowing for errors of this kind. Thus, in the use of a Fteley meter a too rapid vertical motion causes a decrease in the velocity indicated, while with the Price meter the results will be too large. In case it is required to make allowance for errors due to up and down motion, in order to secure exact results, the meter should be tested by moving it vertically through still water and noting the effect.

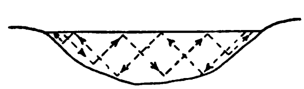

Fig 74. Method of Measurement by Integration.

A method involving the integration of the entire cross-section of a stream, which has been used with satisfactory results by the author, is as follows: The meter is started at one bank and is moved across the stream obliquely, down and up alternately, at an angle of about 45 degrees to the horizontal. This method is illustrated in Figure 74, which represents a cross-section of a stream, and in which the dotted line shows the path of

the meter across the stream; the arrow heads show the directions in which the meter is moved.

In making a run or observation with a meter, the stop watch is started as the gaging begins and the number of times the meter crosses the stream, as well as the time required to move from bank to bank, is recorded. Where the depth of the water in the section varies greatly, it may be advisable to record also the number of times the meter is lowered and raised. It is generally sufficient to cross the stream twice.

This method can be used to advantage where provision has been made for crossing the channel of the stream easily, and where the meter can easily be raised and lowered in the section. This may be impossible if the current is too swift, or if the stage or platform on which the observer stands is too high above the water, or if the water is too deep. It possesses considerable advantage over other methods of current meter observations in the speed with which the gaging can be made, permitting no change in the discharge while the work is going on. In the author's practice this method has been found particularly applicable for streams not too deep for wading; also on flumes where the depth is uniform and a plank can be thrown across upon which to stand. It is also suitable for use in a canal, where the observer stands in a boat, working the meter, while an assistant pulls the boat from bank to bank by a rope stretched across the canal.

CHAPTER II.

METHODS OF FIELD WORK—RATING CURRENT METERS—REDUCTION OF OBSERVATIONS—RATING TABLE—FORMULA FOR DISCHARGE, METHODS AND COMPUTATION OF DISCHARGE—WEIR MEASUREMENTS—MEASUREMENT OF HEAD—CONDITIONS FOR ACCURACY — DISCHARGE TABLE AND CONDITIONS — THE WETTED PERIMETER—COEFFICIENT OF ROUGHNESS—IRRIGATION CANALS—FLOW OF WATER IN OPEN CHANNELS—VELOCITY CURVES—COEFFICIENT OF REDUCTION—SEDIMENT OBSERVATIONS.

METHODS OF FIELD WORK.

The field operations necessary in the measurement of stream flow by current meter comprise two successive steps, as follows:

1. Laying out a sounding range and measuring the cross-section of the stream thereon. 2. Observations of velocity.

Sounding Range. When a current meter is used to determine velocity in a given stream a suitable location is selected for a discharge station, as in the case of the float observations. For meter observations, however, no base line is necessary and only one cross-section is required. This should be as nearly as possible a typical section of the stream; it should be located where the flow is regular and free from natural or artificial obstruction. The water gage should be set so that no minus readings will occur, the zero being placed one or two feet below the lowest known stage of the water. A bench mark should be established to which the zero of the gage is referred; it should be located at some convenient point above high-water mark.

The range having been established, soundings are made at suitable intervals along it. The first sounding should be at the edge of the water, its depth being recorded as zero and its distance from the initial point on the range also recorded. For streams of ordinary size soundings are usually made every 10 or 20 feet; for small streams the interval between soundings is about 5 feet.

Velocity Observations. In a case where the depth of the water is not too great, the observations are made by wading. In some cases where the channel is narrow, a plank or footway is laid from bank to

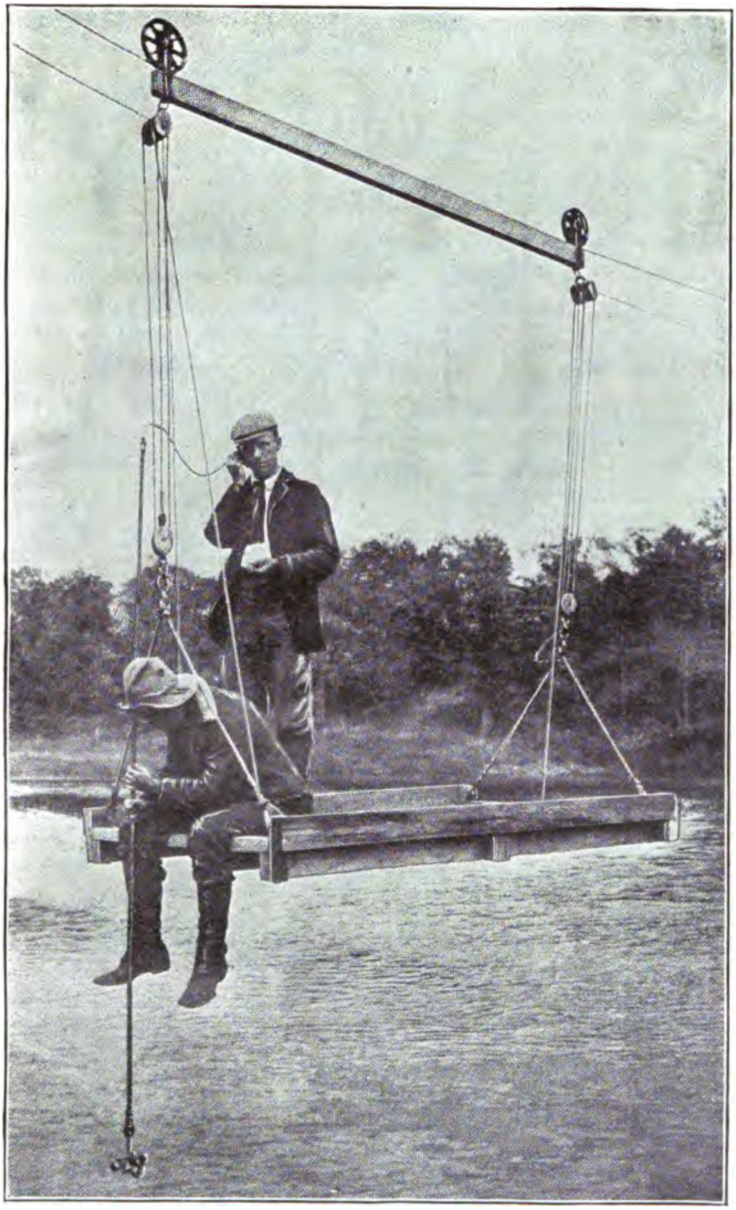

Fig. 75. Measuring Velocity of Water from Suspended Platform.

bank upon which the observer stands while making the observations. When there is a bridge conveniently and suitably located, the discharge station may be located directly beneath it and observations made from the bridge. Where streams are deep it will be necessary to use a boat.

Where a permanent discharge station is required, the arrangement shown in Figure 75 will often be found suitable. This consists of a wire cable stretched securely across the stream, and carrying a movable platform, upon which the hydrographer and his assistant are stationed while making observations. The illustration represents one of the river gaging stations of the United States Geological Survey. The hydrographer holds in one hand his watch while with the other hand he holds to his ear a buzzer to indicate the number of revolutions of the meter wheel during a unit of time. The assistant holds the meter in the water in the required position during the observations. Where the revolutions are counted in this manner each observation is usually for a period of 50 seconds. Where point measurements are made it is customary to make two observations of 50 seconds each at a point, and if these do not all agree, to make a third and a fourth, if necessary, continuing until they are satisfactory. If these observations appear to have nearly equal value the average of all is taken; if one or more are of doubtful value the doubtful ones are rejected.

In cases where a recording register is used with a meter the reading of the dial is noted before and after each observation; the difference between the two readings indicates the number of the meter wheel's revolutions for that observation. The number of seconds required for each observation is also noted; the number of revolutions divided by the number of seconds gives the revolutions per second of time.

Rating Current Meters.

When a current meter is used to determine the current velocity in a given stream, the observed results show the number of revolutions of the meter wheel during a given number of seconds. In order to determine the velocity of the current in feet per second from a meter observation it is necessary to know the ratio between the revolutions per second of the meter wheel and the velocity of the current turning the wheel in feet per second. The individual action of each instrument used must be noted, since it has been found that there is a noticeable difference in the operation of different current meters, even when made from the same patterns and at the same

time. The operation of determining the ratio between the observed results for a current meter is called rating the meter.

The usual method of rating a meter is by running it through still water, the assumption being that the same relation will hold between the turns of the wheel when running through still water as when held in one position in flowing water.

The United States Geological Survey maintains two rating stations for current meters, one at Chevy Chase, Maryland, and one at Los Angeles, California. The apparatus used at Chevy Chase consists of a platform, about 200 feet in length, built along the edge of a small, deep pond, the waters of which are comparatively stagnant. On the outer edge of this platform is a track laid with light, iron rails, on which is placed an ordinary mine car or truck, with an outrigger, so that the meter can be held vertically over the water, and immersed to the required depth. On the platform a measured course of 100 feet is laid off, and the car is pushed by hand, care being taken to pass over every 10 or 20 feet in a given number of seconds so that the same velocity can be maintained from start to finish.

The device used at Los Angeles consists of a cement-lined trough containing water. Above this, and parallel to its length, is stretched an iron cable, suitably supported, on which is a trolley frame with two wheels, by means of which the meter is supported beneath the surface of the water. The meter is propelled through the water over a measured course, usually one hundred feet long, for twenty or more times in succession, at different rates of speed, the speed varying from less than 0.5 of a foot per second to about 6 or 8 feet per second, or even more; the number of revolutions per hundred feet and the number of seconds required to make the run are noted for each run.

In ordinary practice such elaborate equipment is not available and meter rating is usually conducted from a small row boat or skiff.

Method of Rating. Before rating a meter it is a good plan to cause the meter wheel to revolve by hand, counting the number of revolutions or the number of seconds during which it will revolve before stopping, in this manner ascertaining in a general way the condition of the bearings as regards friction. The bearings should at all times be kept well oiled in order to make the friction as nearly uniform as possible.

The field notes are reported in a notebook having sufficient space to enter the results of the computations, thus making a complete

TABLE No. 1.—COMPUTATION FOR RATING. Buff & Berger Current Meter, No. 1017.

OBSERVATIONS AT EASTON, PA., July 15, 1901.

SAML. H. LEA, Observer. W. N. DAVIS and CHAS. ENZIAN, Assistants.

No. of Observations	No. of Revolutions	Time in Seconds	Revolutions per Sec. X	Velocity Feet per Sec. Y	X-Xo	Y-Yo	$(X-Xo)^2$	(X-Xo) (Y-Yo)	REMARKS
1	24	83½	0.29	1.197	−0.94	−3.542	+0.884	+3.329	Fteley Meter, No. 1017.
2	26	33¾	0.78	2.962	−0.45	−1.777	+0.203	+0.800	Meter, attached to frame work in front of bow of boat; submerged 3 feet below surface.
3	26	19¼	1.35	5.195	+0.12	+0.456	+0.014	+0.055	
4	25	59	0.42	1.695	−0.81	−3.044	+0.656	+2.466	
5	26	12½	2.10	8.000	+0.87	+3.261	+0.757	+2.837	Observations made in still water, in upper level of Morris Canal.
6	26	43	0.60	2.326	−0.63	−2.413	+0.397	+1.520	
7	25	30	0.84	3.333	−0.39	−1.406	+0.152	+0.548	
8	26	13	2.02	7.693	+0.79	+2.954	+0.624	+2.334	Length of course 100 feet.
9	26	13½	1.92	7.407	+0.69	+2.668	+0.476	+1.841	Gentle wind blowing across canal. Boat run alternately in opposite directions along the canal. Meter rated by makers, Oct., 1900. Has since been used frequently; it is in good condition. When revolved by hand wheel came to rest in 185 seconds.
10	26	27	0.96	3.703	−0.27	−1.036	+0.073	+0.280	
11	26	21	1.23	4.762	00	+0.023	00	00	
12	26	24¼	1.09	4.124	−0.14	−0.615	+0.020	+0.086	
13	26	16	1.64	6.250	+0.41	+1.511	+0.168	+0.620	
14	26	17½	1.50	5.657	+0.27	+0.918	+0.073	+0.248	
15	26	14¾	1.79	6.780	+0.56	+2.041	+0.314	+1.143	
			18.53	71.084					
		Xo=	1.23	4.739=	Yo		4.811	18.107	

A=3.764. B=0.109. Y=3.711 X=0.174.

record for each rating. A good form of notes is shown in Table No. 1, in which the field observations are given in the three left-hand columns; the reductions are in the remaining columns. The notes also show the date, the locality, the motion, if any, of the water, the force and direction of the wind, the length of the course in feet, and such other information as is necessary. The observer should note when the meter was last rated the amount of use it has had since that time, and the condition of the meter at the time of rating. He should also note the time required for the wheel to come to rest when turned briskly by hand.

The meter, when in place for rating, should be held in position, immersed to a sufficient depth in front of the boat, which is moved through the water at a uniform speed for each observation.

In Figure 76 is shown a good arrangement for attaching a meter

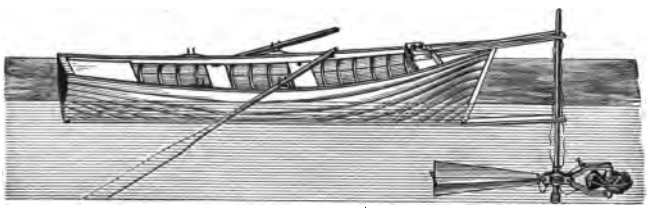

Fig. 76. Method of attaching Current Meter to Boat for Rating

to a boat for rating. The water should be not less than 5 feet deep and the meter should be immersed at least 2 feet. A course 100 feet long is measured off, the extremities being marked by range stakes, so that the observer can note the exact instant of passing each range.

The boat is pulled over the course by assistants on the bank, by means of a light line or rope attached to the bow; a boatman in the boat steers it by means of oars, keeping it from running into the bank. The boat is started before reaching the course so as to acquire the desired rate of speed before passing the first range. It is run over the course a sufficient number of times, at different velocities, varying from ½ foot per second to about 8 feet per second. The observer, at the instant of passing the first range, starts his stop-watch and the registering device of the meter, and stops them at the instant of passing the second range.

Example. In order to explain in detail the operation of rating a current meter, an example taken from actual practice will be given. In this case the meter was held in position in front of a boat, while the boat was run over a measured course in the manner that has been

described. The speed was varied for each run, the results being noted and tabulated as shown in Table No. 1. The field notes, comprising the number of each observation, the number of revolutions of the meter wheel, and the time in seconds required to pass over the course, are entered in the order given, in the three left-hand columns, shown in Table No. 1.

Reduction of Observations.

Graphic Method. In order to determine graphically the relation between the number of revolutions of the meter wheel and the velocity of its motion through the water, for the series of observations, a diagram should be drawn to scale as follows: The observed values are platted on cross-section paper, by co-ordinates, taking the number of revolutions per second as abscissas, represented by the symbol x, and the velocities in feet per second as ordinates, represented by the symbol y. Such a diagram is shown in Figure 77, in which the observed values in Table No. 2 are platted, their positions being designated by small circles. It will be observed that they all fall nearly in a straight line; such a line is called a rating curve. It is assumed that this line will pass through a point representing the mean of the observed values of x and y; this point is located and a line passing through it and swung so as to average the other points, is drawn for the rating curve.

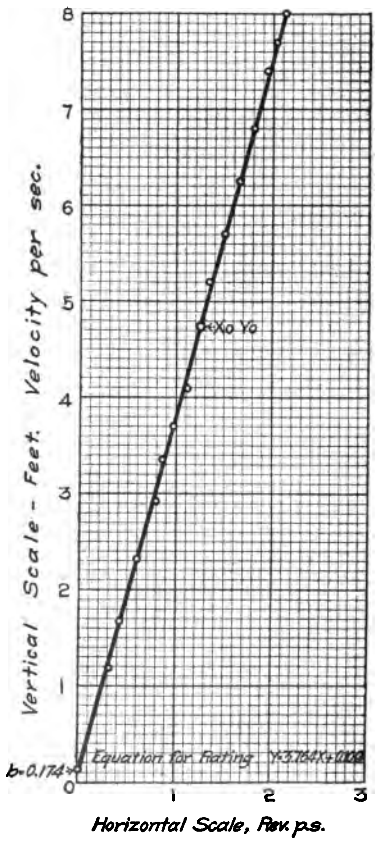

Fig. 77. Rating Curve for Current Meter.

If all the observations for determining velocities were entirely without error, and if there were no friction in the bearings of the wheel, all of the platted values of the several observations would lie in a straight line, passing through the origin of co-

ordinates. It is evident, however, that on account of the resistance due to friction, some velocity of current will be required to start the meter wheel to revolve from a state of rest. This velocity, however small, is appreciable, and must be taken into account in rating a meter. It is expressed in the rating equation by the constant *b*, and is shown on the diagram by the distance from the origin of co-ordinates to the point of intersection of the rating curve with the axis of ordinates. At this point the number of revolutions per second is zero, and the velocity of the current is some appreciable value, which is characteristic for each meter and is usually considered a constant.

The rating curve having been drawn in accordance with the observed values, any intermediate value, within the limits of observation, can be interpolated on the curve, by observation or by measuring with a scale.

Analytical Method. The rating curve for a current meter can be expressed by the equation:

$$y = ax + b, \tag{1}$$

in which b is the distance from the origin of co-ordinates to the point of intersection of the curve with the axis of ordinates, representing frictional resistance; and a is the tangent of the angle made by the rating curve with the axis of abscissas. The values of *a* and *b* could be derived from any two observations at different speeds, but, in order to find the best and most probable values for them a great many observations are usually made in practice.

In making computations to determine probable values for *a* and *b* from a series of observations, the observed values of *x* and *y* are tabulated and *a* and *b* are determined analytically.

A good method to use for such determination is that given in "Theory and Practice of Surveying," by the late Prof. J. B. Johnson This method will be explained in detail by applying it to a rating operation made in actual practice. In the case under consideration the results of a series of fifteen observations are shown in Table No. 1 in the three left-hand columns, which show the numbers of the observations and the observed values of x and y. From this table the mean values of x and y, which are respectively x_0 and y_0, are derived as shown.

Equation (1) can be written: $ax + b - y = 0$. Every observation equation may be written in this form, using corresponding observed values for *x* and *y*. Designating the successive observed values of x and y by corresponding subscripts, the successive observation equations are written:

$$ax_1+b-y_1=v_1; \quad ax_2+b-y_2=v_2; \qquad ax_{15}+b-y_{15}=v_{15} \tag{2}$$

Since *b* enters alike into all of them it is evident that these equations are of equal value for determining *b*. Since the most probable value of a numerously observed quantity is the properly weighted arithmetical mean, and since in this case the equations or observations have equal weight for determining *b*, we can form from the given series of equations a single standard or normal equation which will be the arithmetical mean of the observed equations. Make this equation equal to zero and use for finding the value of *b*. Calling x_0 and y_0 the mean of all the observed values of x and y, we obtain, by adding all the equations together and dividing by their number:

$$ax_0 + b - y_0 = 0 \therefore b = y_0 - ax_0. \qquad (3)$$

Substituting this value of b in equation (2) we have:

$$a(x_1 - x_0) - (y_1 - y_0) = v_1$$
$$a(x_2 - x_0) - (y_2 - y_0) = v_2$$
$$a(x_{15} - x_0) - (y_{15} - y_0) = v_{15} \qquad (4)$$

There is only one unknown quantity involved in this series of equations, but they are evidently not of equal weight in determining this unknown quantity *a*, since its coefficients are different. The relative value of these equations for determining *a* is in direct proportion to the sizes of these coefficients in the respective equations. They should all be weighted in proportion to the values of these coefficients; a convenient way to do this is to multiply each equation through entire by the corresponding coefficient. The resulting multiplied equations then have equal weight and may be added together to produce another normal equation for finding a. In this case the resulting equation is:

$$[(x - x_0)^2]a - [(x - x_0) \quad (y - y_0)] = 0. \qquad (5)$$

In this equation the sign of summation is indicated by brackets thus: [ ]. If this equation had been divided by the number of observations, 15, it would not have been changed so far as the value of *a* is concerned. The mean or most probable value of *a* can be found from equation (5). Substituting the values found in Table No. 1 and reducing, we have: $a = 3.711$. The mean value of *b* is found from equation (3) to be: $b = y_0 - ax_0$. Substituting the values of x_0 and y_0 given in Table No. 2, and the value of a just found, we have:

$$b = 4.739 - (3.711 + 1.23) = 0.174.$$

Then for the meter under consideration equation (1) becomes:

$$y = 3.711 + 0.174,$$

which is the equation for rating.

TABLE No. 2.

RATING TABLE FOR FTELEY METER,

Buff & Berger, No. 1017.

J. McNEAL, Computer, July 20, 1900.

Revolutions per Second	Velocities in Feet per Second	Revolutions per Second	Velocities in Feet per Second	Revolutions per Second	Velocities in Feet per Second
0.00	0.109	0.72	2.819	1.44	5.529
0.02	0.184	0.74	2.894	1.46	5.604
0.04	0.260	0.76	2.969	1.48	5.679
0.06	0.335	0.78	3.044	1.50	5.755
0.08	0.410	0.80	3.120	1.52	5.830
0.10	0.485	0.82	3.195	1.54	5.906
0.12	0.561	0.84	3.271	1.56	5.981
0.14	0.636	0.86	3.345	1.58	6.056
0.16	0.711	0.88	3.421	1.60	6.131
0.18	0.787	0.90	3.497	1.62	6.207
0.20	0.862	0.92	3.572	1.64	6.282
0.22	0.937	0.94	3.647	1.66	6.357
0.24	1.012	0.96	3.722	1.68	6.433
0.26	1.088	0.98	3.798	1.70	6.508
0.28	1.163	1.00	3.873	1.72	6.583
0.30	1.238	1.02	3.948	1.74	6.658
0.32	1.313	1.04	4.024	1.76	6.734
0.34	1.389	1.06	4.099	1.78	6.809
0.36	1.464	1.08	4.174	1.80	6.884
0.38	1.539	1.10	4.249	1.82	6.759
0.40	1.715	1.12	4.325	1.84	6.835
0.42	1.690	1.14	4.400	1.86	7.110
0.44	1.765	1.16	4.475	1.88	7.185
0.46	1.840	1.18	4.551	1.90	7.260
0.48	1.916	1.20	4.626	1.92	7.336
0.50	1.991	1.22	4.701	1.94	7.411
0.52	2.066	1.24	4.776	1.96	7.486
0.54	2.142	1.26	4.852	1.98	7.561
0.56	2.217	1.28	4.927	2.00	7.637
0.58	2.292	1.30	5.002	2.02	7.712
0.60	2.367	1.32	5.077	2.04	7.787
0.62	2.443	1.34	5.153	2.06	7.862
0.64	2.518	1.36	5.228	2.08	7.937
0.66	2.593	1.38	5.303	2.10	8.002
0.68	2.769	1.40	5.379	2.12	
0.70	2.744	1.42	5.454	2.14	

TABLE No. 3.—DISCHARGE MEASUREMENT.

BEAR CREEK, CARBON CO., PA., Aug. 14, 1902.

No. of Section	Upper Range			Lower Range			Mean Area Sq. Ft.	Time in Seconds	Velocity of Float Ft. per Sec.	Discharge in Cub. Feet per Sec.	REMARKS
	Mean Depth Feet	Width Feet	Area Sq. Ft.	Mean Depth Feet	Width Feet	Area Sq. Ft.					
							A		V	Q	Lower range 1500 feet above Iron bridge.
1	6.5	8	52.0	6.2	8	49.6	50.8	364	0.549	27.9	
2	11.3	10	113.0	11.5	10	115.0	114.0	311½	0.642	73.2	Ranges 200 feet apart.
3	12.0	10	120.0	11.9	10	119.0	119.5	227	0.881	105.3	
4	13.5	10	135.0	13.7	10	137.0	136.0	213¾	0.936	127.3	Floats used; Tin cylinders 2 inches in diameter.
5	13.8	10	138.0	14.1	10	141.0	139.5	211¼	0.947	132.1	
6	11.4	10	114.0	11.9	10	119.0	116.5	265½	0.753	87.7	
7	3.9	6.5	25.4	4.9	7.5	36.8	31.1	390	0.513	16.0	
			697.4			717.4	707.4			570.1	

Rating Table.

The algebraic expression given above is not convenient for rapid use in the field and should therefore be transformed into numerical terms suitable for determining the relation between observed values within the limits of probable current velocities. This is best done by constructing a rating table for the meter, giving directly the velocity per second of the current in terms of revolutions of the wheel. Such a table, if carried out sufficiently far, does away with all multiplication in the field notes, the values being taken directly from the table.

In Table No. 2 is shown a rating table for the meter that was used in the series of observations recorded in Table No. 1. Corresponding velocities in feet per second are shown for every two-hundredth part of a revolution per second, from a state of rest, to the highest observed value. For smaller fractions of a second than those given in the table the corresponding velocities are found by interpolation.

By the use of a rating table much tedious calculation is avoided since, for any observed rate of velocity of revolution, the corresponding velocity of current, in feet per second, can be found in the table. A rating table for a given meter is generally found to be fairly constant until the meter becomes injured, or the friction noticeably increases by the wearing away of the more delicate parts of the bearings.

It is a good plan to occasionally test the friction of the bearings of a meter by giving the wheel a smart turn with the hand and noting the length of time it will run before stopping. The time will of course become shorter as the friction of the bearings increases.

Reduction of Discharge Measurements.

In computing the discharge of a stream, in which the current velocities have been determined by means of floats or by current meter observations, the cross-section of the stream is divided into sections and the mean velocity of each section ascertained by observations, as previously described. The area of each section is obtained by multiplying the width by the mean depth. The discharge is the product of the area by the mean velocity of the given section. The discharge of the stream or of the entire cross-section is the sum of the partial discharges.

Formula for Discharge.

The discharge of a stream or of a section of a stream may be expressed by formula as follows: $Q = av$ (I), in which Q is the

quantity of water discharged in a given unit of time; a is the area of the section in square feet; and v is the velocity of the current, expressed in feet per unit. This is the fundamental formula for the discharge of any given section of a stream. It is equally applicable for expressing the entire discharge of a stream when suitable values are given to the factors of the equation. Generally, in computing discharge of streams, the symbol Q, designating quantity, is expressed in cubic feet of water per second of time. In such a case the symbol a, designating area, is expressed in square feet; and the symbol v, designating velocity, is expressed in lineal feet per second.

Discharge by Floats.

An example, showing the method of computing stream discharge when floats are used to determine current velocities, is given here.

Referring to Figure 63 let *a* and *b* represent the platted cross-sections on two sounding ranges, at the upper and lower extremities respectively of a measured base line for a given discharge station, as A-B, Figure 62. The dimensions of the respective sections are determined by measurement, as previously explained. In the present case the mean velocities in the respective sections were ascertained by rod floats. Since there is some variation in the dimensions of the two end cross-sections, a mean cross-section is interpolated for convenience in computation.

This information is tabulated as shown in the accompanying Table No. 3. The discharge of each section, shown in the last column, is easily determined by substituting the known values, a and v, in formula (I), and solving the equation to determine Q. The sum of the partial discharges is the total discharge of the stream.

Discharge by Current Meter.

When the current velocities in the several sections of a stream at a discharge station, are determined with a current meter, the work is done in one cross-section, as previously explained. In the example of computation of discharge measurements that will now be considered, the cross-section is divided into sections having a uniform width of 10 feet, except the two end sections, which are not so wide. Depths are determined by soundings at the division points, also midway between them, where the meter observations are made. A plat of the cross-section is given in Figure 78, in which the division lines of the sections are shown as full lines; those midway of each section, where meter observations are made, are shown as dotted lines.

The mean velocity obtained in each vertical is assumed to represent the mean velocity for a portion of the section on either side of the vertical, which is taken parallel to the course on the stream, and

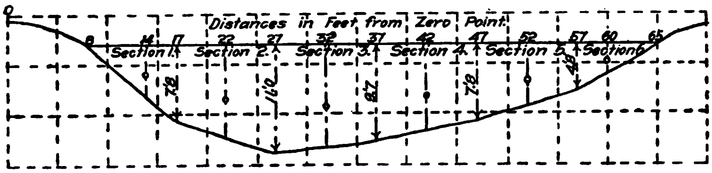

Fig 78 Measurement of Discharge by Current Meter.

extending half-way to the points of observation on either side, or to the limits of the section where the observation is made.

The results of the several observations and the computations are entered in the observer's note book. A good form of notes is shown in Table No. 4, which contains the field notes of the gaging under discussion.

In laying off a sounding range at a discharge station, some fixed point on the range should be selected for the zero point of all measurements on that range. In a case where subsequent measurements are to be made at different stages of the water, this point should be far enough up on the bank to be above high water.

The first sounding should be at the edge of the water, and its distance from the initial point should be entered in the note book, the depth being registered as zero. The last sounding should be at the further edge of the water; its distance from the initial point should be noted and its depth should be recorded as zero, as in the case of the first sounding. The depths and the distances to the intermediate soundings are noted. The mean depth of each section is either taken as the depth of water at the place where the meter is read, or else is obtained by adding the depths of water on either side, half-way to the next point of observation, adding to this twice the depth where the meter is run, and dividing the aggregate by four. This mean depth, in feet, multiplied by the width in feet, gives the area of the section in square feet. Depths are usually taken to the nearest tenth of a foot.

In the sections of a stream nearest to the shore, special care should be taken in the observations, so as to get a true expression of the mean velocity of the water, applicable to the whole section. In many instances the current near the shore is sluggish, and often there are eddies or back currents at some stages of the water. Due allowance should be made for such factors in the computations, and also for

TABLE No. 4.—GAGING MADE JULY 21, 1904,
By S. H. LEA and J. WILLIAMS.
Gage height, 6.5. River Stationary.
Buff & Berger Meter, No. 1017.

At Fernaula, Ala., on Cahaba River.
Total area 406.1 sq. feet.
Mean velocity 4.40 feet per Sec.
Discharge 1785 cub. feet per Sec.

No. of Section	Soundings		Observations					Rev. per Sec.	Vel. Feet per Sec.	Section			Dis-charge of Section	REMARKS
	Distance from Zero Point	Depth	Depth of Obser-vation	Time in Sec-onds	Dial Reading					Width	Mean Depth	Area		
					Begin	End	Diff.							
1	8 14 17	00 5.2 7.8	6 10	50 50	617 675	675 733	58 58	1.16	4.48	9	3.9	35.1	157.2	
2	22 27	9.4 11.0	"	50 50	680 746	746 813	66 67	1.23	4.74	10	9.4	94.0	445.6	
3	32 37	10.3 9.7	"	50 50	820 881	881 943	61 62	1.21	4.66	10	10.3	103.0	480.0	
4	42 47	8.7 7.8	"	50 50	950 1006	1006 1062	56 56	1.12	4.33	10	8.7	87.0	376.7	
5	52 57	6.3 4.8	"	50 50	1070 1120	1120 1170	50 50	1.00	3.87	10	6.3	63.0	243.8	
6	60 65	3.0 00	"	50 50	1170 1214	1214 1258	44 44	0.88	3.42	8	2.4	24.0	82.1	
										57		406.1	1,785.4	

dead or still water. In some cases, in order to get a true expression of discharge of a stream, it may be advisable to leave out of the computations a portion of the cross-section near the shore, in which there is no perceptible current. In computing the average depths of the triangular sections at each end of the cross-section, the depth at the shore is taken as zero, this being added to the other depths, and the total divided by four, as in the case of a trapezoidal section. In determining the mean velocity of a triangular section, the meter is not held on the vertical half-way between the shore and the side of the adjacent section, as in the case of a trapezoidal section. The author's practice is to use a vertical about two-thirds of the distance from the shore to the side of the adjacent section.

In making discharge computations it is not necessary in practice to carry them out to a degree of refinement not warranted by the exactness of the field measurements. Usually two places of decimals will express with sufficient exactness, both the observations and the results of stream measurements. Velocities should be given in feet and hundredths of a foot per second; for uniformity, the gage readings may be expressed in hundredths of a foot, although it is customary to express them to the nearest five-hundredth of a foot. It is sufficiently exact to give the computed results of a discharge measurement to decimals of a foot per second; any closer statement would be useless refinement, not warranted by the degree of exactness with which the field work can be done. The field work should be conducted with great care, but on the other hand, the computations in the office, while they should be accurately made, should not be carried out to a degree or refinement inconsistent with the original work.

Computation of Discharge.

In Figure 78 is shown the cross-section of a stream, platted from the notes given in Table No. 4. The vertical broken lines indicate the boundaries of adjacent sections, while the dotted lines show the verticals on which meter readings were taken; the latter are midway between the sides in each trapezoidal section, and two-thirds of the distance from the shore to the side of the adjacent section in each triangular section. Soundings were made at these several points, as shown in the notes. In this case there were no eddies or still water next to the shore; the triangular sections were made shorter than the intermediate trapezoidal sections, but otherwise were treated in the same manner, in making the observations and in computing the results.

Referring to Table No. 4 it is seen that observations were taken at six-tenths of the depth below the surface in each vertical, thus obtaining the mean velocity of the section in one operation.

The discharge in each section is obtained by multiplying together the area and the mean velocity; the total discharge is obtained by adding together the partial discharges. The mean velocity of the stream is found by dividing the total discharge by the area of the cross-section or by the sum of the areas of the several sections.

In measurements of stream discharge by the use of a current meter, accuracy of results is merely relative as compared with other methods, that by the use of floats for instance. The measurement of flowing water in an open channel, can not usually be determined with absolute accuracy, since the quantities to be measured are not fixed but fluctuate considerably in a short period of time, often during the process of measurement. The elevation of the water surface is subject to the influence of pulsations, extending over intervals of from 30 to 50 seconds, and causing vertical oscillations of appreciable extent. The velocity of the current is liable to vary at different points in the same section, and even at the same point during successive moments. Taking these facts into consideration, it is evident that in the measurement of a stream, there is room for variation from absolute accuracy in results; this variation may be anywhere from 2 to 5 per cent. in the total.

Weir Measurements.

In some instances, in streams of moderate size, it is practicable to build weirs for gaging the flow. A weir is an obstruction, generally of timber, built across the channel of a stream, through or over which, the water is caused to flow, thus affording opportunity for convenient measurement. This is probably the most accurate method of measurement applicable to small streams.

Weirs are of various forms, the shape varying according to local conditions and requirements. In some instances, even in streams of considerable size, where dams have been built for power purposes, such dams, if of proper form, may be used as weirs with good results. A suitably constructed dam may consequently be considered as one general type of weir, while a specially constructed weir is the other general type.

By observing the head on the weir, that is the height of water above the crest of the weir, computations of the discharge can be made. Such computations are made by the use of empirical formulas, which vary according to the type and form of weir used.

MILL DAMS AS WEIRS.

On a stream that is utilized for manufacturing purposes, where the flow is interrupted by backwater from dams, it is frequently very difficult to find a reach suitably located for a discharge station. In some instances, where the slope of the stream is considerable, a place suitable for meter measurements can be found just below a dam, where the current will not be affected by backwater. In such a place, however, the flow is subject to change, due to the opening or shutting of the gates regulating the supply of water to the mill wheels.

Fig. 79. Masonry Dam at Holyoke, Mass., with 2 feet of Water on Crest.

Under such conditions the method best suited for obtaining satisfactory measurements is by using a dam of suitable construction as a weir. Such a dam should be free from leakage; it should have a level, even crest and a uniform cross-section, with sufficient storage of water above it to prevent too swift a current in the water just before reaching its crest. This current is called the velocity of approach; it will be referred to further on in the discussion.

Masonry dams are generally better adapted for use as measuring weirs than dams built of timber, since the former are more likely to

be water-tight and to be smooth and level on top than the latter, which are liable to settle out of line and to become uneven on the crest. In many cases, however, well constructed timber dams are found that are adapted for accurate work.

A good form of dam, suitable for use as a weir, is shown in Figure 79, which is a photograph of a masonry dam at Holyoke, Mass. When a dam has been selected for use as a weir, a careful survey should be made to determine the crest line and the cross-section of dam. This information is important since the coefficient of flow varies according to the form of cross-section of the dam.

Formulas for Discharge.

Many experiments have been made to determine discharge formulas applicable to dams of various forms of cross-section. No single formula can be given that will be suitable for general use in computing the discharge over a dam. In making computations for discharge in such a case, it is customary to select some form of dam for which a formula or a coefficient has been derived by experiment, and which conforms most nearly to the form of dam upon which the measurement has been made.

The formula which expresses in general terms the flow of water over a dam or weir is, in its simplest form:

$$Q = C.\ L.\ H^{\frac{3}{2}} \qquad (1)$$

in which Q is the volume of discharge in cubic feet per second; L is the effective length of the crest in feet; H is the depth in feet of water flowing over crest of dam; C is a numerical coefficient, called the coefficient of discharge.

The value of C may be written: $C = 2/3\ K\ \sqrt{2g} = m\ \sqrt{2g}$, in which g is the acceleration of gravity, say 32.2 feet per second; K and m are constants determined by experiment. Substituting these values for C, equation (I) may be written:

$$Q = \frac{2}{3} K \sqrt{2gH} \times LH = mLH\sqrt{2gH} \qquad (2)$$

Then, in order to determine the discharge over a dam, its crest is measured and its effective length determined; also the dimensions of its cross-section, as previously stated. The head or depth of water H, above the crest of the dam, is not measured directly over the crest, because of the vertical contraction of the water there; it must be measured in quiet water, a few feet above the dam. This having been done, all the factors in the second term of the equation are known except the coefficient of discharge. As has been stated, this coefficient varies with the form of cross-section of the dam,

and must be derived from some dam of similar form, whose coefficient has been determined by experiment.

In computing the discharge over the crest of a dam, the width of crest, slope, form of apron, etc., must be taken into account in selecting the value of the coefficient C, as has been stated. In a case where the profile of the dam is irregular, varying in height and shape at different places along the length of the dam, the crest should be divided into sections in such a manner that all corresponding points in a given section will be, as nearly as possible, at the same elevation. The discharge of each section is then computed separately, the aggregate being the total discharge over the dam.

In some cases, where a dam has an irregular profile, for rough calculations, or computations of flood discharges, the average crest elevation is taken and the discharge calculated for the entire dam at one operation. This method gives results that are too small, since the discharge over the lower part of the crest is greater in proportion to the head than that over the higher portions of the crest.

If a gaging is made on a dam when the mill gates are open, the water flowing through the gates must be measured and added to the quantity flowing over the dam in order to determine the total discharge of the stream. Usually the water flowing through the gates can be measured with the aid of a current meter as previously described. In case a turbine mill-wheel is used the discharge through the wheel can be determined directly from the rate of revolution of the wheel itself, or from the known rating of the turbine.

Such a gaging as has been described, when carefully made, will afford fairly accurate results. When a dam is of good construction, without leakage, and with conditions favorable as to smoothness of crest and uniformity of flow, the results of a gaging thereon will often prove more satisfactory than a meter measurement made under unfavorable conditions. On the other hand, dams that are leaky, and that have ragged, uneven crests are unsuited for use as weirs and measurements made on them will have little practical value.

MEASURING WEIRS.

Weirs constructed for the express purpose of gaging the flow of streams are in extensive use in the western part of the United States and in other countries where irrigation is practiced on a large scale. The measurement of stream discharge by the use of weirs is especially applicable in irrigation where water is usually conveyed in streams and canals of moderate size and where accurate measurements are required.

When a weir is built across a stream for the purpose of gaging the flow, it is generally intended either for permanent use or for a series of accurate measurements; it should, therefore, be located and built with a view to obtaining the best results in the way of accuracy. A weir should be located, as nearly as possible, with its face at right angles to the axis of the stream. The upper face should be vertical, and the crest of the opening or notch, over which the water flows, should be truly horizontal. The weir should be strongly built, with solid foundation and substantial bracing. The planking should be rigid, so as to prevent vibration of the framework or crest, and the sides and bottom should be properly joined to the surrounding material in order to avoid leakage under or around the weir. An apron or floor of planks should be placed on the lower side of the weir to receive the falling water and prevent undermining.

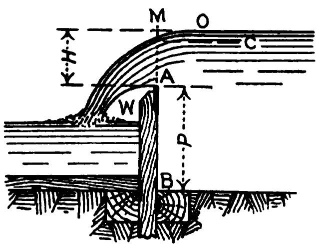

Fig. 80. Cross Section of Weir.

There are in common use two general forms of weirs, as follows:

a The rectangular weir, with an opening whose sides are vertical;

b The trapezoidal weir, with an opening whose sides are inclined at a slope of one vertical to four horizontal. These will be discussed in order.

For any form of measuring weir the horizontal edge of the opening or notch is called the crest of the weir. When a weir has no end contractions the crest only is made sharp, as shown in section in Figure 80. For a weir with end contractions the inner edges of the opening, both horizontal and vertical, should be made sharp, so that the water in passing through it touches only along a line.

For ordinary work the edges of the planks in which the opening is cut, are chamfered off at an angle of about 45°, as shown in section in Figure 81. For accurate work, and in localities where the edges are subject to abrasion by drift passing over the weir, the edges, both horizontal and vertical, should be made with a thin plate of iron, firmly attached, as shown in section in Figure 82.

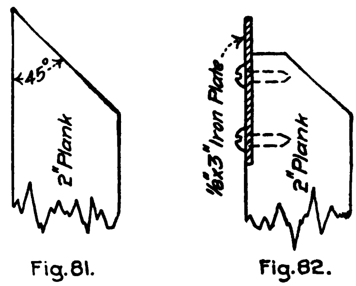

Fig. 81. Fig. 82.
Details of Crest.

Rectangular Weirs.

The rectangular form of weir is the one which is ordinarily meant when the term weir is used, and will be so considered in this discussion. Rectangular weirs are of two kinds; those without end contractions and those with end contractions.

When a weir has its opening or notch extending entirely across the channel of a stream, so that the ends of the notch coincide with the sides of the channel, it is called a weir without end contractions. Such a construction is shown in perspective in Figure 83, and in plan in Figure 84.

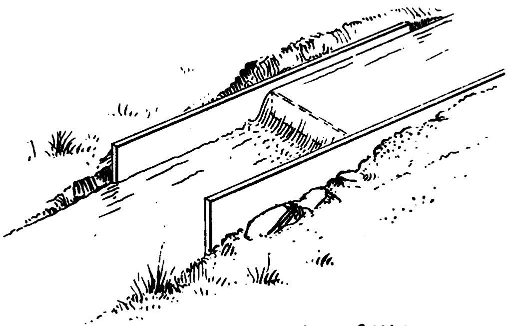

Fig. 83. View of Weir without End Contractions.

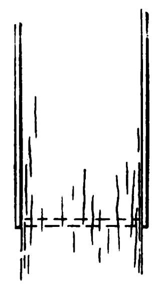

Fig. 84. Plan of Weir without End Contractions.

When the opening in a weir extends only part way across the channel, as shown in perspective in Figure 85 and in plan in Figure 86, the weir is evidently contracted at the ends, and is called a weir with end contractions.

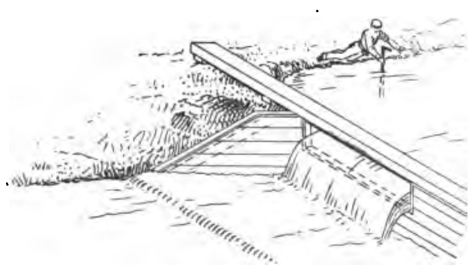

Fig. 85. View of Weir with End Contractions.

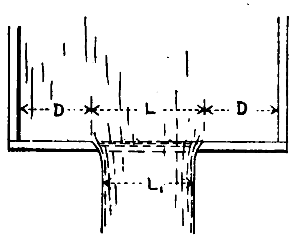

Fig. 86. Plan of Weir with End Contractions.

The late J. B. Francis, as the result of a series of elaborate experiments and a thorough investigation of the flow of water over weirs, derived a formula for weir discharge, which is commonly

called the Francis formula. This formula, with suitable modifications, adapted to the form of weir under consideration, is generally used in computing the flow of water over weirs. Both forms of rectangular weirs will be discussed separately, and the application of the discharge formula to each form of weir will be shown.

Weirs Without End Contraction.

When a weir has its crest extending entirely across a stream, there is no contraction in the sheet of water flowing over it, except at the top and bottom of the sheet; this is called the crest contraction. The form of crest contraction is illustrated in Figure 80, in which the top and bottom contractions are shown at M C and at A respectively. In computing the discharge over a weir of this kind the crest contraction must be taken into account.

It has been seen that the formula for computing the flow of water over a dam or weir, in which end contractions are not considered, is:

$$Q = C\,L\,H^{\frac{3}{2}} \qquad (1)$$

in which C is the coefficient of discharge, the other factors having the significance previously explained.

As has been previously stated, the coefficient of discharge varies according to the form of cross-section of the dam or weir. For a weir with a sharp crest, as in the case of a measuring weir, the formula derived from the Francis formula is:

$$Q = 3.33\,L\,H^{\frac{3}{2}} \qquad (3)$$

This formula is correct in cases where there is no velocity of approach, that is, where the water has no appreciable velocity just above the weir. In practice such a condition, for the form of weir under consideration, is never found, since water in flowing over a dam or weir, whose crest extends across the full width of the channel, must necessarily have an appreciable current in order to produce discharge. The formula just given must therefore be corrected for the velocity of approach before it can be applied to the computation of discharge over a weir without end concentrations.

Velocity of Approach.

The velocity of approach is the mean velocity with which the water flows through the channel leading to the weir, at the point where the head is measured. In a case where there is an appreciable velocity of approach in a stream above a weir, the surface of the water will have an appreciable slope for some distance above the

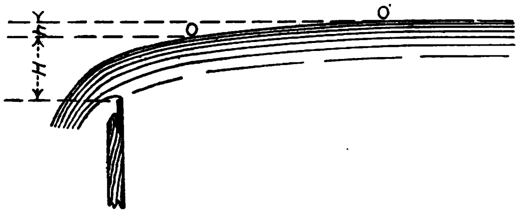

Fig. 87. Section on Axis of Stream.

region of quiet water, a few feet above the weir. This is shown on an exaggerated scale in Figure 87, in which H is the head above the weir, measured in quiet water, several feet above the crest, and h is the velocity head or the head due to the slope. It is evident that the true head, producing the flow over the weir is H + h. This value must be substituted in formula (3) to obtain the correct discharge. In order to find h the velocity of approach must be determined. The determination of the velocity of approach in the current may be effected by the use of floats or by current meter, as previously described. It is customary, however, to determine it by formula, in which case the following method may be used:

Let v = the mean velocity of approach;
H = the head of water flowing over the weir, measured in quiet water;
h = the velocity head;
Q = the approximate quantity of water flowing over the weir, $= 3.33\,L\,H^{\frac{3}{2}}$;
A = the cross-sectional area of the channel just above the weir.

Then from equation (1),

$$Q = A\,v: \; v = \frac{Q}{A} = \frac{3.33\,L\,H^{\frac{3}{2}}}{A} \tag{4}$$

and, to find the velocity head,

$$h = \frac{v^2}{2g} = \frac{v^2}{64.4} \tag{5}$$

The value of h is found by substituting observed values in equations (4) and (5). Equation (3) then becomes:

$$Q = 3.33\,L\,(H + h)^{\frac{3}{2}} \tag{6}$$

This is the simplest form of discharge formula for a weir with no end contractions, and one that will give fairly accurate results when applied to a weir constructed under proper conditions.

Weirs with End Contractions.

The most common form for rectangular weirs is that in which the crest does not extend the full width of the channel, that is, where one or both ends of the opening are contracted. The effect of such con-

traction is to prevent or diminish the velocity of approach in the stream to such an extent that it will be inappreciable. When suitable contraction is made, it will therefore obviate the necessity of taking into account the velocity head h, thus, eliminating a troublesome factor from the discharge equation. The equation expressing discharge over a weir with end contractions will be the following modification of the simple form of the Francis formula:

$$Q = 3.33\, L_1\, H^{\frac{3}{2}} \qquad (7)$$

in which L_1 is the effective length of the crest.

Effective Length of Crest.

It is seen that in the formula just given, in place of L, denoting actual length of crest, the factor L_1, denoting effective length of crest, is used. The effective length is not the same as the actual length of crest, as will be seen from the following explanation.

The effect of end contractions in a weir is to diminish the area of cross-section of the stream passing through the weir, making its width less than the actual length of the crest of the weir. This is illustrated in Figure 86, in which L is the measured length of the crest and L_1 is the width of the stream issuing from the weir. It is seen that L_1 is shorter than the actual length L of the crest. In such a case L_1 is called the effective length of the weir; it is found by applying a correction to the measured length. For a weir with end contractions, the value of L in the discharge formula is, therefore, not the measured length of the crest but its effective length.

Complete Contraction.

The amount of contraction or of diminution in width of the issuing stream from a weir with end contractions, depends upon the relation between the distance from the sides of the opening to the parallel sides of the weir, also the depth of water above its crest. When this distance, as D, Figure 86, is about twice as great as the head H, there is practically no further change in the contraction of the water with any increase in the distance D. In such a case the contraction is said to be complete.

A weir is said to have one or two complete contractions according to whether one or both ends of the opening are contracted in the manner described. In some cases weirs are contracted midway of their length; there may be all degrees of contraction in weirs, from complete contraction to no contraction.

The amount of diminution in the width of the sheet of water

flowing over the crest, when the crest contraction is complete, increases with the depth over the crest, or the head H. In other words, the effective length of the crest decreases as the head increases. From experiment Mr. Francis found that the effect of complete contraction on a weir is to diminish the effective length of its crest by one-tenth of the head H for each contraction. This may be expressed by the following equation:

$$L_1 = L - 0.1\ n\ H. \tag{8}$$

in which n = the number of complete contractions, and the other factors have the same meanings as have been previously given. When there are two complete contractions, n = 2, and the equation becomes: $L_1 = L - 0.2\ H$.

Substituting this value of L in equation (7) the formula for discharge becomes:

$$Q = 3.33\ (L - 0.2\ H)\ H^{\frac{3}{2}} \tag{9}$$

for a weir with two complete end contractions, where the velocity of approach is negligible.

Where there is an appreciable velocity of approach, allowance must be made for it, as in the case of a weir without end contractions. This is done by substituting in the equation for discharge a value for H that has been determined from experiment as being suitable for the form of weir under consideration.

The experiments made by Messrs. Fteley and Stearns indicate that in the case of a weir with two complete end contractions, proper allowance for velocity of approach is made by substituting H + 2.05 h for H in the simple form of discharge formula.

Trapezoidal Weir.

It has been seen that, in the case of a rectangular weir with complete contractions, the effect of the contraction increases in proportion to the depth of water flowing over the weir crest. This has the effect of making the effective length of weir decrease with the height. It was in the effort to devise a form of weir, in which the effective length of crest is the same as the measured length for all depths, that the trapezoidal form of notch or opening was devised.

The trapezoidal weir, which is also called the Cippoletti weir, from the name of its originator, Cesare Cippoletti, an Italian engineer, was designed to overcome by its form the effect of end contraction on the discharge, and to make the discharge proportional to the measured length of crest, while using the simple form of discharge formula.

The fundamental idea of the trapezoidal weir is that the cross-sectional area of the stream of water flowing through it increases sufficiently with increase in depth to exactly balance the loss due to end contraction, thus allowing the use of the simple form of discharge formula, without requiring correction for end contraction.

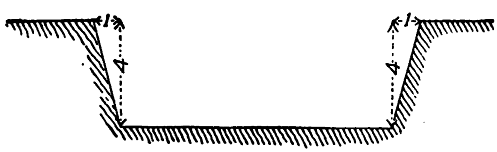

Fig. 88. Form of Trapezoidal Weir.

A trapezoidal weir has an opening whose sides, instead of being vertical, as in the case of a rectangular weir, slope outward at an inclination of one horizontal to four vertical. This form, which is illustrated in Figure 88, is equivalent to that of a rectangular weir with a triangle added at each end. The theory upon which this form of weir is based, which was derived from experiment and calculation, is that the flow through the added triangles is sufficient to balance the loss due to end contractions. If this theory is true the discharge will be the same as that over a rectangular weir with the same length of crest, without end contractions, and with no appreciable velocity of approach. In such a case the discharge formula would be the simple form of the Francis formula: $Q = 3.33 \text{ L H}^{\frac{3}{2}}$

Cippoletti found, however, from experiment, that the coefficient used in the Francis formula should be increased about one per cent. in order to give correct results. This being done, the discharge formula for the trapezoidal weir is: $Q = 3.367 \text{ L H}$ (10)

This is correct when there is no velocity of approach. In case there is an appreciable velocity of approach, the velocity head h, must be found and the correction applied, as in the case of a rectangular weir.

Measurement of Head.

In all weir measurements it is necessary to know accurately the depth of water over the crest of the weir; this depth being expressed in the discharge formula by the symbol H. As previously stated, this depth or head must be measured in still water, usually at a distance of several feet upstream from the weir.

In measuring the head care must be taken to avoid waves, ripples and other disturbances of the water surface; also to provide against capillary attraction when using a rule or measuring rod to obtain a reading.

For very accurate work, in which it is required to determine very closely the true level of the water surface, a hook gage should be

used. This consists of a long, graduated rod, provided at its foot with an upturned hook or point. It is arranged to slide vertically in a fixed support, to which is attached a vernier, indicating on a scale the height of the point. When the zero of the scale and of the vernier are together, the point of the hook gage should be under water and at the exact level of the weir crest. In order to find the depth of water over the crest the hook, which should previously be lowered below the water surface, is raised slowly until the point just reaches the surface. The reading of the vernier will then give the depth of water corresponding to the head H. When a hook gage is used the water level is usually taken in a vessel or side chamber, which communicates by a pipe or conduit with the main channel. The vessel, being protected from wind and other disturbing influences, the water contained therein has a calm, smooth surface, suitable for accurate observations. The use of the hook gage is not common in ordinary survey work, in which the field methods employed do not require such great refinement of observation. It is especially adapted for use in hydraulic experiments and observations, and in the measurements where great accuracy is required, as in rating water wheels, turbines, etc.

For ordinary work the following is a good method to use in determining the head: A post or stake is set in the water where it is quiet, at some convenient point, a few feet above the weir, so as to be easily accessible from shore. The top should be cut off square, and should be horizontal and at the exact level of the weir crest.

The depth of water is measured with a graduated rod or rule, placed vertically on top of the post, the reading of the water surface on the side of the rule being carefully observed.

A convenient method for obtaining an accurate reading of the water surface is described and illustrated in a booklet written in 1898 by Mr. Robert C. Gemmell, State Engineer of Utah. In using this method a stake is set in the water, with its top at the level of the weir crest, as just described. On the top of the stake a carpenter's square is held in a vertical position in the manner illustrated in Figure 85 and shown in detail in Figure 89. A slide made of tin, with a sharp point on its upper edge, is used to determine the exact water surface, as shown. This form of slide is illustrated in Figure 90. In use it is placed on the square in such a manner that when

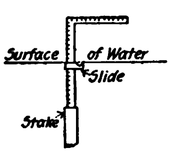

Fig.89. Arrangement for Measuring Head.

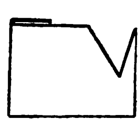
Fig.90. Details of Tin Slide.

the square is held in a vertical position, the upper edge of the slide and the point are in the same horizontal line. The slide is lowered until it is well below the surface of the water; it is then gradually raised until the upper edge just reaches the surface, which is indicated by the appearance of a pimple on the surface of the water, immediately over the point.

Another method of measuring the head is by means of a glass water tube, set vertically at some convenient point below the weir, and graduated to feet and decimals, with its zero level with the crest of the weir. It is connected with still water above the weir by means of a pipe of suitable size and length. This device, however, should not be used when there is danger from freezing.

Conditions for Accuracy in Weir Measurement.

The formulas given for weir discharge, as has been previously stated, are empirical, that is, they have been derived from experiment. Each formula will give results in practice that will be correct within about one per cent, when applied to the form of weir for which it is given, provided proper conditions are observed.

The results obtained by the use of the formulas are exact, or nearly so, only so far as experimental knowledge goes; it is, therefore, safe to apply a given formula, only within the limits of the experiments upon which it is based.

From experimental investigations the following conditions have been found necessary in order to obtain accurate results:

1. The channel leading to the weir, on the upstream side, should be straight and of constant cross-section, with its axis perpendicular to and passing through the middle of the weir; it should be of sufficient size and length for the water to flow with uniform velocity, without internal agitation or eddies.

2. For a weir with complete end contractions the following conditions are necessary: *a* The opening must be in a plane surface, perpendicular to the course of the stream. *b* The opening should have sharp edges on its crest and sides, on the upstream face; for depths less than 5 inches the thickness of its walls at the point of discharge should be not over one-fourth the depth, and for depths of from 5 to 24 inches, the thickness of the walls should be not over one-tenth of the depth. *c* The distance of the crest of the weir from the bottom of the stream should be at least three times the depth of water on the weir crest. *d* The distance of the vertical sides of the opening from the sides of the channel should be at least twice the depth of water over the crest, or of the head H. *e* The

length of the crest should be at least three times the depth of water over it, or of the head H. *f* The depth of water flowing over the crest should be not less than three inches.

3. In order to be negligible, the velocity of approach for weirs with crests up to three feet long, and with a depth of 12 inches, should not be greater than six inches per second; for crests from three to six feet long, and with a depth of 24 inches, it should not exceed eight inches per second. In all these cases the cross-section of the channel of approach should be at least seven times that of the weir.

4. The sheet of issuing water should be perfectly free from the walls below the crest in order to allow free circulation of air. For short weirs it is sufficient that the lateral walls of the lower channel be free from the sides of the weir. In such a case, when air passes freely underneath, the level of the water in the lower channel has no influence on the discharge unless it reaches the level of the crest.

5. The depth of water should be measured accurately, at a point that is not affected by the flow, and that is free from influence by wind or other disturbing factor. The height or head should be read to within one-three-hundredth of the depth in order that the error may be within one per cent.

6. The weir should be carefully constructed and located. It should not vary more than four degrees from being perpendicular to the channel. The crest of the weir should be truly horizontal.

When the conditions just mentioned are observed, and when observations are carefully made, the gaging of stream flow by weir measurement is the most accurate of any method that has been devised.

Tabulation of Measured Discharges.

With the rise or fall of the water surface in a stream, at a given discharge station, there is a corresponding increase or decrease in the discharge. If a number of discharge measurements have been made, at various stages of the water, the results should be tabulated, with a record of the mean velocity, the volume and the gage height for each observation.

Discharge Table.

Such a record as has been described constitutes a discharge table, which may be used as a basis for computations showing intermediate values between those that have been observed. In Table No. 5 is given a discharge table showing measured discharges at different stages of water in a canal. For convenience each stage is taken as being exactly two feet distant in height from the next higher and

TABLE No. 5.

DISCHARGE TABLE FOR CANAL.

Depth of Water Feet	Area of Cross-Section Square Feet	Mean Velocity Feet per Second	Discharge Cubic Feet per Second
2.0	24.0	1.24	29.8
4.0	56.0	1.62	90.7
6.0	96.0	1.89	181.4
8.0	144.0	2.10	302.4
10.0	200.0	2.29	445.8

TABLE No. 6.

DISCHARGE TABLE FOR SAN JOAQUIN RIVER, AT HERNDON, CALIFORNIA.

No. of Gaging	Gage Height Feet	Area of Cross-Section Square Feet	Mean Velocity Feet per Second	Discharge Cubic Feet per Second
1	4.00	1,198	1.67	1,995
2	3.85	1,273	1.52	1,937
3	6.65	2,262	3.28	7,419
4	8.00	2,769	4.05	11,225
5	3.00	1,005	0.68	677
6	2.60	730	0.45	332
7	2.55	703	0.38	270
8	4.10	1,350	1.78	2,406
9	9.33	3,839	4.15	15,942
10	2.75	722	0.59	424

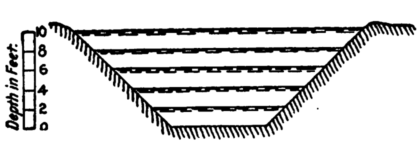

Fig. 91. Cross Section of Canal, showing Different Stages of Water.

lower stages. The form of cross-section of the canal is shown in Figure 91. For convenience the form is shown regular, with regular slopes. In practice, however, such regularity in cross-section is seldom found, since ordinary streams, or even canals, after considerable use, have rather irregular cross-sections. In such cases values interpolated between observed discharges will necessarily be only approximate, though sufficiently close for practical use.

For a practical example a discharge table giving the results of field observations on the San Joaquin River, in California, is shown in Table No. 6. This is taken from a report of the United States Geological Survey and is shown as an example of actual field work.

Discharge Curve.

The rates of flow of a given stream, at a discharge station, may be shown graphically in the form of a discharge curve, within the limits of observed values. In order to form such a discharge curve, the results of the various gagings, as entered in the discharge table, are platted on cross-section paper with the gage heights as ordinates and the discharges as abscissas, all values being referred to the origin of co-ordinates.

When this is done the result of each gaging will be shown as a point, at some designated place on the paper. If there are a number of these points, well distributed according to different stages of the stream, it will usually be found that they will all lie approximately in the path of a parabolic curve. Such a curve is sketched through or near the points; the surveyor, from observation and knowledge of local conditions, should give greater weight to some points than to others.

In Figure 92 is shown a discharge curve drawn from the data

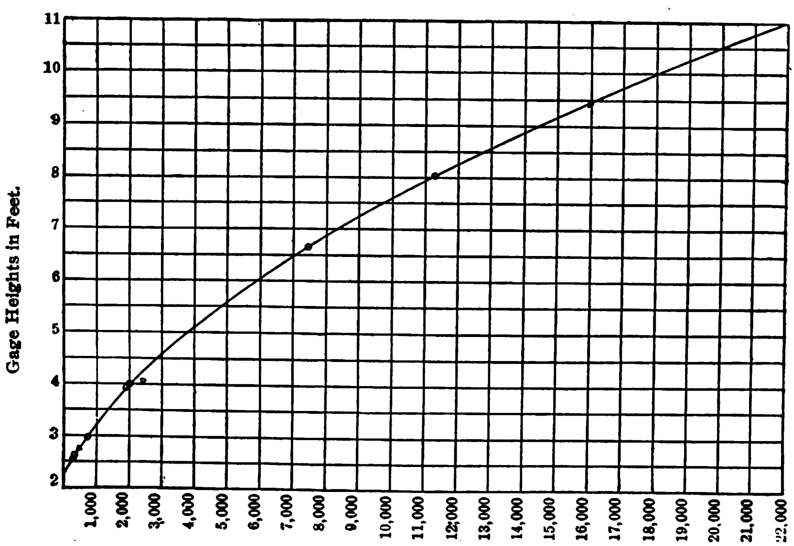

Fig. 92. Discharge Curve for Herndon Station, on San Joaquin River, California.
(From U. S. Geological Survey).

given in Table No. 6. The gage heights are platted as ordinates, in feet, and the discharge values are platted as abscissas, in cubic feet per second, in the manner that has been described; their positions are shown by the small circles. The curve drawn through the several points is the discharge or rating curve; it is seen to resemble in form a parabola. For any values lying within the limits of the platted values, points are interpolated on the curve, whose corresponding ordinates and abscissas represent respectively the gage heights and discharge values required.

Rating Table.

When a discharge curve has been drawn, in the manner just described, a rating table may readily be prepared, showing the discharge for every tenth of a foot of gage height, within the limits of the observations. Such a rating table is simply a numerical expression of the discharge curve previously described.

In preparing a rating table, the first figures, representing the lowest values, are taken from the discharge curve drawing, beginning at the lower left hand corner. The lowest abscissa, intersecting the axis of ordinates at the nearest tenth of a foot to the origin of co-ordinates, is followed from left to right until it intersects the curve, and the value represented by the distance is entered in the table opposite the tenth of a foot taken. The abscissa corresponding to the next tenth of a foot in height is then followed out, as just described, and its length from the axis of ordinates to the curve at the right, is also found and recorded. This process is continued for each succeeding tenth of a foot of gage height; the corresponding distances to the curve are tabulated as discharges.

When a table has been prepared in this manner it will be found that there is an increasing value for the discharge, and that the difference between the successive values is constantly increasing. Owing, however, to the small scale to which such a sketch is necessarily drawn, the figures taken from the drawing do not always have this constantly increasing value; some being proportionately too large and others too small. In order, therefore, to smooth out the curve it is a good plan to set off between the lines of the rating table, the differences in the quantity of discharge, making a third column. Upon examining this column several points are quickly detected where the differences are not regular. After considering these it will be seen that a slight adjustment of the differences, and the addition or subtraction of a small amount to or from the figures of discharge, will smooth out these irregularities. This adjustment

should be made and, as a check upon the accuracy of the work, the resulting figures, after the rating table has been smoothed out, should be platted upon the original drawing, in order to determine by inspection, that the rating table, as finally adjusted, is accordant with the observations. This method of graphic construction avoids difficulties and liability to error in the use of the higher mathematics, and its accuracy is well within that of the original data.

A rating table should be complete in all respects. It should contain the discharge for the lowest as well as the highest gage heights occurring during the period for which it is applicable. The discharge should be given for every tenth of a foot in gage height and, if the gage has been read to hundredths, the table should give values for each half-tenth in height. The volume of discharge is usually given to the nearest cubic foot. This is sufficiently close

TABLE No. 7.

RATING TABLE FOR SAN JOAQUIN RIVER,

AT HERNDON, CALIFORNIA.

Gage Height	Discharge	Gage Height	Discharge	Gage Height	Discharge	Gage Height	Discharge
Feet	*Sec. Feet*	*Feet*	*Sec. Feet*	*Feet*	*Sec. Feet*	*Feet*	*Sec. Feet*
2.3	80	4.5	2,900	6.7	7,540	8.9	14,080
2.4	165	4.6	3,080	6.8	7,810	9.0	14,400
2.5	250	4.7	3,260	6.9	8,080	9.1	14,760
2.6	340	4.8	3,440	7.0	8,350	9.2	15,120
2.7	430	4.9	3,620	7.1	8,620	9.3	15,480
2.8	520	5.0	3,800	7.2	8,890	9.4	15,840
2.9	610	5.1	4,000	7.3	9,160	9.5	16,200
3.0	700	5.2	4,200	7.4	9,430	9.6	16,560
3.1	820	5.3	4,400	7.5	9,700	9.7	16,920
3.2	940	5.4	4,600	7.6	10,008	9.8	17,280
3.3	1,060	5.5	4,800	7.7	10,316	9.9	17,640
3.4	1,180	5.6	5,012	7.8	10,624	10.0	18,000
3.5	1,300	5.7	5,224	7.9	10,932	10.1	18,400
3.6	1,450	5.8	5,436	8.0	11,240	10.2	18,800
3.7	1,600	5.9	5,648	8.1	11,552	10.3	19,200
3.8	1,750	6.0	5,860	8.2	11,864	10.4	19,600
3.9	1,900	6.1	6,088	8.3	12,176	10.5	20,000
4.0	2,050	6.2	6,316	8.4	12,488	10.6	20,400
4.1	2,220	6.3	6,544	8.5	12,800	10.7	20,800
4.2	2,390	6.4	6,772	8.6	13,120	10.8	21,200
5.3	2,560	6.5	7,000	8.7	13,440	10.9	21,600
4.4	2,730	6.6	7,270	8.8	13,760	11.0	22,000

for all ordinary purposes, since stream measurements are not usually made to a degree of refinement that will require any closer figures.

In Table No. 7 is given a rating table for the San Joaquin River at Herndon, Cal., which was prepared in the manner just described from the discharge curve shown in Figure 92. The discharge curve, discharge table and rating table shown are all taken from the report of the United States Geological Survey, previously referred to; they are given as representing good examples of actual practice for such work.

The length of time during which a rating table can safely be applied to observations at a given discharge station should be determined by the surveyor and noted upon the table in order that it may not be used beyond proper limitations. Where the channel is constantly changing, as is the case in most streams, a table cannot be used for many weeks or months unless it be referred to the readings of heights as interpreted by additional soundings.

Discharge by Formula.

It is sometimes required to compute the discharge of a stream throughout a given stretch or portion of its length, under conditions where it is not convenient to undertake close measurements, or where approximate values are sufficiently close for the purpose required.

In some cases, after determining the discharge of a stream by one of the mehods that have been described, it is advisable to compute the flow by some different method for purposes of comparison.

In either of the above cases it is customary, when an alternative method is required, to compute the discharge by formula; and for this purpose the well known formulas of Chezy and of Kutter are commonly used.

The Chezy formula, which is the fundamental formula for stream discharge, is:

$$Q = A\ V \qquad (1).$$

in which Q = the discharge of the stream, usually in cubic feet per second;

A = the area of channel cross-section, usually in square feet;

V = the velocity of flow, usually in feet per second.

The various methods of ascertaining current velocities by floats and by meter, which have been discussed in this manual, require the measurement of velocity by direct observation. In applying the Chezy formula, however, to the determination of stream discharge,

the mean velocity of a stream is considered a function of the slope and of the wetted perimeter of a stream. This may be expressed by formula as follows:

$$V = c\sqrt{RS} \tag{2}$$

in which R = the hydraulic radius or the hydraulic mean depth of the channel;

S = the sine of the surface slope, for which, owing to its small value, the surface slope is substituted;

C is a variable coefficient, depending upon the nature of the channel.

Slope.

The slope of a stream, or rather of a section of a stream, is the difference in elevation between the upper and lower ends of the section, commonly called the fall, divided by the distance or the length of the section. The value of the slope may be expressed by an equation thus:

$$S = \frac{F}{L} \tag{3}$$

in which F = the fall in feet from the upper to the lower end of the section;

L = the length of the slope section in feet.

The slope section should be of suitable length; such length will depend largely upon the nature of the stream, the accuracy required in the results and the size and length of the stream under consideration.

Thus, in the case of a canal or an irrigation ditch, where the values determined by formula are compared with those obtained by direct measurement, sections of 100 or 200 feet in length are commonly considered.

In the case of a river or other large stream, where the object may be to determine discharges at maximum stages of the water, slope sections varying in length from several hundred feet to several miles, are used. In such cases the extremities of the slope sections are located, as closely as possible, at the principal points of change of slope in the stream. In the gaging of the Mohawk River by the New York Barge Canal survey, the river from Herkimer to Cohoes, a distance of 84.1 miles, was divided into thirteen slope sections, each section being from 2.7 to 11.3 miles long.

It is difficult to ascertain accurately the slope of the water surface in a stream, since in nearly all streams, there are pulsations in the water, causing the surface to rise and fall locally. In most streams

the slope of the bottom is far from uniform, and the flow of water in any given section is more or less influenced by the flow in the adjacent section, above or below. For example, if a section 500 feet long has a slope of 5 feet to the mile, and the section of the same length, next below, has a fall of 4 feet to the mile, the influence of the steeper slope of the upper section will be felt in the lower section. For this reason it is a good plan to consider a number of adjacent sections, comprising a considerable portion of the length of a given stream, in one computation, being careful to take into account the diversity of cross-section at various places in the length.

In determining the slope of the surface of a stream, levels are taken of the water surface at each end of the slope section, and referred to some datum or bench mark. A good plan is to set firmly a stout wooden stake below the water surface at each end of the slope section, and then to drive a nail into the top of each stake, so that the nail head will exactly coincide with the water surface. Levels can then be run from one stake to the other; the difference in elevation between the two nail heads, divided by the distance between the stakes, will give the slope.

In case it is not possible to have the nail heads exactly at the water surface the results will be the same if they both have the same relative position with respect to the water surface. Under ordinary conditions this method of determining the slope will give accurate and satisfactory results.

The Wetted Perimeter.

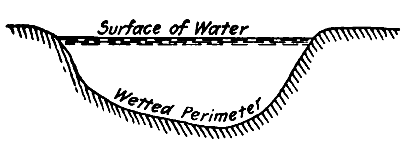

Fig. 93. Cross Section of Stream, showing Wetted Perimeter.

The wetted perimeter is that portion of a stream channel that is in contact with the water. Thus in Figure 93, in which is shown the cross-section of a stream, that portion of the perimeter of the channel that is shown below the water surface is the wetted perimeter. The form of outline of the wetted perimeter of a stream has an important influence upon the velocity of the current.

The Hydraulic Radius.

The hydraulic radius, which is sometimes called the mean radius of a stream, is the mean depth of the channel below the water sur-

face. The value of the hydraulic radius for any given cross-section of a stream can be obtained by means of the equation:

$$R = \frac{A}{P} \tag{4}$$

in which R = the length of the hydraulic radius, usually in feet;
A = the area of wet cross-section, usually in square feet;
P = the length of the wet perimeter, usually in feet.

The Coefficient C.

In computing discharge by the use of the Chezy formula, it is necessary to find a value for the coefficient C, that is applicable to each individual case where the formula is used. It was formerly the practice among hydraulicians to consider C a constant, each investigator assigning a value to it corresponding to that derived from experiment.

In modern practice, however, C is treated as a variable coefficient whose value is dependent upon the size, shape, slope and degree of roughness of the channel. In determining the value of C for any given case it is customary to make use of the auxiliary formula of Ganguillet and Kutter, commonly known as Kutter's formula. This formula is expressed in the following equation:

$$C = \frac{41.6 + \frac{.00281}{s} + \frac{1.811}{n}}{\frac{1 + \left(41.6 + \frac{.00281}{s}\right) n}{\sqrt{R}}} \tag{5}$$

In this equation R and s have the same significance as in the Chezy formula and the new factor *n* is called the coefficient of roughness.

THE COEFFICIENT OF ROUGHNESS.

The value of the coefficient of roughness, n, was determined by Kutter for six different classes of channels, only two of which were natural channels and, therefore, of direct interest to the hydrographic surveyor. These two values are as follows:

N = 0.025 for channels in earth, brooks and rivers;

N = 0.030 for streams with detritus and aquatic plants.

Since the death of Kutter the late P. J. Flynn, Member American Society Civil Engineers, from an extended series of experiments, derived values for n for a number of different channels. The complete results of these experiments were published in Mr. Flynn's book on the "Flow of Water in Irrigation Canals," and need not be given here. The following values for n, given by Mr. Flynn as the results of his experiments, are applicable to natural channels and canals:

$n = .0225$ for canals in earth above the average in order and regimen;

$n = .025$ for canals and rivers in earth, of tolerably uniform cross-section, slope and direction, in moderately good order and regimen, and free from stones and weeds;

$n = .0275$ for canals and rivers in earth, below the average in order and regimen;

$n = .030$ for canals and rivers in earth, in rather bad order and regimen, and having stones and weeds occasionally, and obstructed by detritus.

$n = .035$ for rivers and canals with earthen beds, in bad order and regimen, and having stones and weeds in great quantities.

$n = .05$ for torrents encumbered with detritus.

IRRIGATION CANALS.

A series of experiments on the flow of water in irrigation ditches and canals was conducted in Utah in 1897 by Prof. Samuel Fortier, under the auspices of the United States Geological Survey and of the agricultural experiment station of Utah. The results of these experiments were embodied in a paper written by Prof. Fortier and published as one of the Water Supply and Irrigation papers of the United States Geological Survey. This paper contains a number of values for n, applicable to irrigation ditches and canals, these values having been derived from the results of the experiments just referred to. The following values for n are taken from this paper:

$n = 0.0175$ for canals in earth, in excellent condition, well coated with sediment, regular in cross-section, and free from vegetation, loose pebbles and cobbles.

$n = 0.020$ for canals in earth, in good condition, lined with well packed gravel, partly covered with sediment, and free from vegetation.

$n = 0.025$ for canals in earth, in average condition, having few sharp bends, and being uniform in cross-section; the water slopes and bottom being lined with sediment and minute algæ, or composed of loose, coarse gravel and fragments of rock less than 2 inches in diameter, and free from vegetation.

$n = 0.030$ for canals in earth, in rather poor condition, having the bed partially covered with debris; or having comparatively smooth sides and bottom, with bunches of grass and weeds projecting into the water, and with aquatic plants growing in the channel.

n = 0.035 for small ditches, having a rough, uneven bed; and for canals in earth, in fairly good condition, but partially filled with aquatic plants.

n = 0.040 for canals in earth, the channels of which are about half full of aquatic vegetation.

n = 0.050 for canals in earth, the channels of which are about two-thirds full of aquatic vegetation.

From his experiments Prof. Fortier derived a number of conclusions, among them being the following:

a The coefficient of friction in canals well lined with sediment, in good condition and long in use, is less than has usually been supposed.

b The effect of water plants in checking the flow and lessening the capacity of irrigation canals may be much greater than a rough, uneven channel.

c Roughness of perimeter in a small ditch exerts a greater influence in retarding flow than the same degree of roughness exerts in a large canal or a river.

Example. An example will be given, showing the application of the Chezy formula to the computation of discharge. The measurements and observations were made in the Logan, Hyde Park and Thatcher canal, near Logan, Utah, being conducted as one of the experiments just mentioned. The sides of the channel were smooth and coated with sediment. The bottom consisted of earth, gravel and pebbles. The value assigned to n is 0.0250. A discharge station was laid off, 100 feet in length, and an average of three cross-sections, at the two extremities and midway of the discharge station, was taken for the mean cross-section; this is shown in Figure 94.

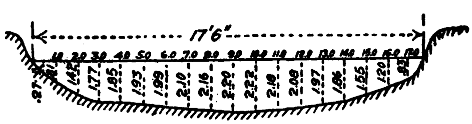

Fig. 94. Cross Section of Canal, showing Subdivisions.

The following values were obtained from measurement:

A = 30.6 square feet = area of water section;
P = 18.9 lineal feet = wetted perimeter;
S = 0.06 per hundred feet = slope.

The hydraulic radius is obtained by substituting known values in the equation

$$R = \frac{A}{P}, \text{ which then becomes: } R = \frac{30.6}{18.9} = 1.62$$

By substituting in Kutter's formula the values given here, a value is found for $c = 63.16$. The values of the several known factors are then substituted in the Chezy formula: $V = c\sqrt{RS}$, from which $V = 1.97$. The fundamental discharge formula is then applied and the value of Q is found to be 60.23 cubic feet per second. This value for discharge agreed closely with the measurements made with a current meter.

The Flow of Water in Open Channels.

The phenomena connected with the flow of water in open channels have been the subjects of much study and observation by various hydraulicians. A great deal has been learned about this subject, although the theory of the flow of water is still incomplete and the laws governing it are not sufficiently understood to allow of going beyond the data acquired from experience. There are, however, certain conditions and principles attending the flow of water, which are sufficiently well known to be considered as practically fixed, and which may be stated in the form of rules or laws. The well known formulas of Chezy and of Kutter are generally accepted as correct, although they are empirical, being based upon the results of observation and experiment. The same is true in a general way of all other formulas or laws that are applied to the flow of water in open channels.

Vertical Transverse Velocity Curves.

If we imagine a flowing stream to be intersected at right angles to its axis by a vertical plane, different points in that plane will have different velocities or rates of flow. The bottom and sides of the channel retard the flow of the water close to them in proportion to their roughness, the retardation being due to the influence of eddies in the water and also to the friction of the flowing water against the perimeter of the channel. The velocity at the surface of the water has been found to be somewhat less than that a little lower in the section.

The retardation of the surface velocity has been attributed to several different causes; one cause is said to be the rising by vertical motion, of the lower water to the surface, after being checked in its flow by coming in contact with the rough places in the perimeter of the channel. Mr. Frederick P. Stearns has attributed the reduction of surface velocity to the general retarding by friction of the layers of water adjacent to the banks of the stream; this water rising to the surface, and thereby making the water surface at the edges of

the channel higher than at the center, and causing a flow of the slowly moving water from the sides toward the middle, thereby decreasing the surface velocity of translation, depressing the point of maximum velocity, and lowering in general the filament of mean velocity.

This is an ingenious theory and, in the opinion of the author, is applicable to streams of moderate size. For large streams, however, it is not thought that this theory will hold good. In the author's experience on the Mississippi River he knows of at least one instance where, during high water stage, the water surface in the river was higher on one side of the channel than on the other, the difference in elevation being something like one-tenth of a foot. In another instance the surface of the water in this river was reported to be actually higher in the middle of the channel than at either edge.

The friction of the surface of flowing water against the air has a retarding influence upon the velocity of flow and, in the case of a strong wind blowing upstream, there may be a decided effect upon the surface velocity, also upon the positions of the maximum and the mean velocities. The author has noted the effect of a stiff wind upon the water surface in the Mississippi River, both when blowing upstream and also in the opposite direction. In the former case waves of considerable size would be formed over the entire water surface, the size of the waves increasing with the force of the wind. In the case of a wind blowing downstream, there would be but slight agitation of the water surface; the only perceptible effect would be the formation of ripples or an appreciable acceleration of the surface velocity.

The depression of maximum velocity in the channel is known to be more pronounced with an increase in the roughness of the perimeter, in the steepness of the banks and in the ratio of depth to width. In the case of a wide, shallow stream, where the bottom merges imperceptibly into the banks, maximum velocity occurs, under normal conditions, at or very near the surface of the center of the stream.

On the other hand, in a deep, narrow channel, as for example, in a canal or open conduit, with vertical sides, the maximum velocity occurs at a considerable distance below the water surface; as indicated by recent experiments, this depression may amount to as much as one-third, or even two-fifths, of the total depth. In such cases the depression of the filament of maximum velocity must result in a lowering of the filament of mean velocity. The surveyor should therefore bear in mind that while current observations at six-tenths

depth give fair values for mean velocity in shallow streams, this ratio should be increased to about two-thirds depth in the case of canals and flumes and narrow natural channels.

In Figure 95 is illustrated a vertical transverse section of a stream, showing lines of equal velocity in different parts of the cross-section. It will be seen that the line of minimum velocity is the one nearest the perimeter; that the velocity increases toward the surface until the maximum velocity is reached, a short distance below the surface. On account of the resistances on the perimeter of the channel and at the surface of the water, the maximum velocity of a stream, in a straight reach, is generally found over the deeper part of the channel and always below the surface, except when wind is blowing downstream at a velocity equal to or greater than that of the current. The line of mean velocity in each section is shown by the heavy broken line in the figure; it is seen to be about six-tenths of the depth below the surface in each section, in accordance with the principle previously explained.

Horizontal Velocity Curve.

If we imagine a horizontal plane to be passed through the water at the place where the cross-section shown in Figure 95 was taken, a foot below the water surface, the current velocities at that depth, if

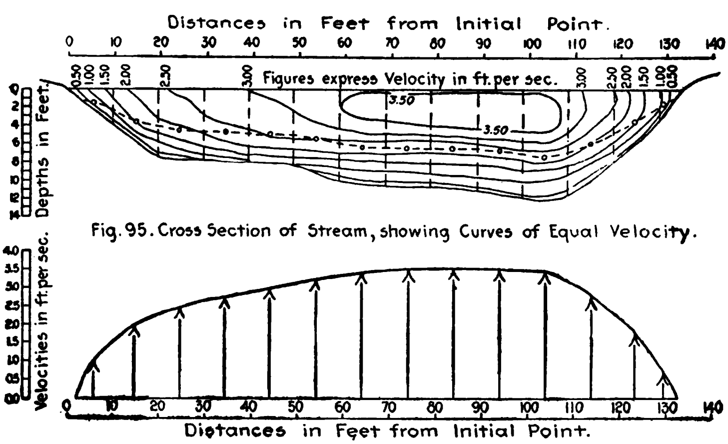

Fig. 95. Cross Section of Stream, showing Curves of Equal Velocity.

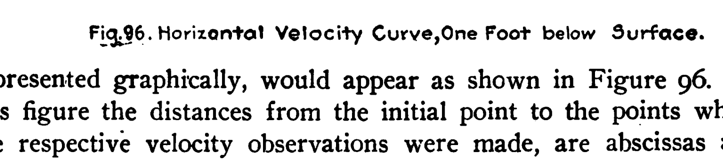

Fig. 96. Horizontal Velocity Curve, One Foot below Surface.

represented graphically, would appear as shown in Figure 96. In this figure the distances from the initial point to the points where the respective velocity observations were made, are abscissas and the velocities are ordinates. A line passing through the points thus

located is called a horizontal velocity curve; it resembles in form a parabola. A curve of similar form will be obtained by platting in this manner the current velocities in a horizontal plane at any given depth between the water surface and the bottom of the channel. The greatest velocities are seen to be over the deepest part of the channel, in accordance with the principles previously stated.

In practice the horizontal velocity curves of streams will not usually be found as regular and symmetrical as that shown in the figure. Local conditions of roughness of perimeter or of obstructions to flow, causing slack water and eddies, will affect the shape of the horizontal velocity curve for any given stream. In general, however, such a curve will resemble a parabola in form.

Vertical Longitudinal Velocity Curve.

If the stream whose cross-section is shown in Figure 95, be intersected by a vertical plane along its axis, the relative rate of flow at different depths may be represented graphically in the manner shown in Figure 97. If the different velocities are represented by horizontal lines whose lengths are proportional to the respective velocities, a curve passing through the outer extremities of the lines thus drawn, will resemble a parabola, whose axis is a short distance below the surface.

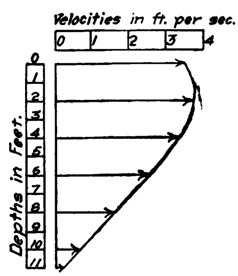

Fig. 97. Vertical Velocity Curve on Axis of Stream.

In the measurement of streams it is not essential to know the exact mathematical form of a vertical velocity curve for a given stream. It is, however, important to know the relation between the surface velocity, the mid-depth velocity, the maximum velocity and the minimum velocity of a stream or of a section of a stream, in order to be able to compute the flow with reasonable accuracy when any one of these is known; and so that, if the current velocity of the measured at some known point in a section the mean velocity of the entire section can be calculated.

The Coefficient of Reduction.

It has been shown that in a given stream the surface velocity is somewhat greater than the mean velocity; that the maximum velocity is below the water surface, but above mid-depth; and that the point or filament of mean velocity is from six-tenths to two-thirds of the total depth below the surface of the water. The rela-

tion between the surface velocity and the mean velocity is important in the use of surface floats, and in using current meters when the current velocity is measured only at or near the surface since, in such cases a coefficient must always be applied in order to ascertain the mean velocity in the vertical section in which the measurement is made.

In determining the proper coefficient to apply for current observations at the surface, or at any given depth, recourse must be had to the results of experiments and observations that have been made by hydraulicians and by hydrographic engineers. The following general rules are given as being in accordance with good practice, and as representing the results of careful and thorough investigations.

For ordinary streams of moderate size it is generally true that the mean velocity in the section or portion of the cross-section where the observation is made is nine-tenths of the surface velocity of the section. If the surface velocity is determined only at the center of the channel, or at the place of maximum surface velocity, the mean velocity for the entire cross-section is about eight-tenths of the surface velocity found. In such cases 0.9 and 0.8 will be the respective values of the coefficient of reduction to be applied in order to obtain the mean velocity required.

For rivers of considerable size, the values of the coefficient that have been given will vary somewhat, the true value depending largely upon the shape and size of the channel and the nature of the wetted perimeter. The coefficient would be greater for large, deep rivers, with smooth, uniform channels; it would be least for small, shallow streams, with rough beds. In most cases the value of the coefficient will be found between the limits of 0.8 and 0.9. The variation of the coefficient to be applied to the surface velocities is such, therefore, as to render this method of obtaining mean velocities unsuitable for use when accurate results are required. In the case of rapids or in time of high floods it is often impossible to ascertain any but surface velocities, and in such cases the use of a coefficient for determining mean velocities from observed surface velocities is necessary.

A great many observations and experiments have been made by different investigators to determine the relation between the velocity at mid-depth and the mean velocity in a vertical section of a stream. In the accompanying Table No. 8 is given the results of observations derived from some of the best known experiments that have been made in order to determine current velocities.

TABLE No. 8, SHOWING THE RELATION BETWEEN MID-DEPTH VELOCITY AND MEAN VELOCITY IN A VERTICAL SECTION OF A STREAM.

OBSERVATIONS MADE AT MID-DEPTH.	Coefficient of Reduction for Obtaining Mean Velocity.
Humphrey and Abbott, on Mississippi River	0.98
Gen'l. T. G. Ellis, on Connecticut River	0.94
Wheeler and Lynch, on Merrimac Flume	0.95
H. A. Pressey, average of 78 velocity curves on streams in New York State	0.94

It will be seen that there is a variation of 4 per cent. between the highest and lowest coefficients given. Mr. H. A. Pressey, in a paper entitled "Observations on the Flow of Rivers in the Vicinity of New York City," which was published by the United States Geological Survey, states that there was a variation of 5 per cent. in the observed velocities of the different streams measured by him. In view of these facts it is usually more satisfactory, in obtaining mean current velocity, to measure the velocity of a stream at the point of mean velocity, than to measure the velocity of mid-depth and then apply a coefficient.

CROSS-SECTIONS OF MINIMUM RESISTANCE.

In accordance with the Chezy formula, a channel or conduit of circular cross-section is of the form that offers the least resistance to the flow of water, since in such a form the wetted perimeter is a minimum and the mean depth or the hydraulic radius is a maximum for any given cross-sectional area.

For open channels a semi-circular form of cross-section would, therefore, conform more nearly than any other to the requirements of easy flow. Such a form of conduit is seen in the Sterling flume, a wooden conduit of semi-circular cross-section used in conveying water for power and for irrigation purposes in some of the Western States.

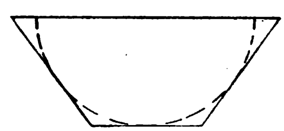

Fig. 98. Cross Section of Minimum Resistance.

For a ditch or a canal it is not usually practicable to make the cross-section semi-circular in form, but the nearer the cross-section approaches that form the less will be the resistance to flow. In designing a form of canal or ditch for maximum flow the following method is applicable: Draw to scale a semi-circle of

the same area as that of the required cross-section. Draw the side slopes of the channel as tangents to the arc and connect them at the bottom by a tangent to the arc, drawn horizontally; the resulting figure will be similar to that shown in Figure 98, this will give a somewhat larger cross-sectional area than required, but the accumulation of silt in the channel will generally reduce it.

In a case where the slope of a proposed ditch or canal is steep and it is desired to produce a minimum or a reduced flow, the cross-section of the channel should be made wide and shallow with flat side slopes.

Measurement of Stream Flow Under Ice.

It is frequently required to measure the flow of streams that have been frozen over and become coated with a solid ice cover. In such cases the only practicable method of measuring current velocities is with a current meter, since the water surface is not accessible for the use of floats. The author has made a number of current measurements in ice-covered streams among the Pocono Mountains in Pennsylvania, in which the use of a current meter afforded satisfactory results. In many cases the measurements were made under a solid ice cover of from three to six inches in thickness. In making such measurements a path or channel, from one to three feet wide, was cut in the ice from bank to bank, and normal to the axis of the stream. Care was taken to make the edges of the cut as regular as possible and to remove all the loose ice from the water, allowing no tilted or inclined pieces in the channel, and no loose pieces to escape under the ice downstream.

The velocity measurements were made either by velocity observations at several points in each vertical, or by the integration method, according to the size of the stream and the convenience of observation. These methods were used in preference to single point observations for mean velocity, on account of the uncertainty of the position of the point of mean velocity.

It is evident that the form of vertical velocity curve for a stream flowing under an ice cover will not be the same as for the same stream in an open channel. In the former case the surface velocity is retarded considerably by friction of the water against the ice cover; in many instances, especially in small streams, the flow is under head.

From the results of measurements made by the author and from observations of other engineers, it appears that there are in such a vertical velocity curve two points of mean velocity, one point being near the surface, and the other almost three-fourths of the total

depth below the surface. According to Mr. Pressey's paper, to which reference has been made, these points of mean velocity are situated respectively at thirteen-hundredths and seventy-three-hundredths of the depth, for the streams whose measurements are given in the paper mentioned.

In many cases it may be preferable to make the velocity measurements in an ice-covered stream at mid-depth in each vertical and to apply thereto a coefficient to obtain the mean velocities. The value of this coefficient for ordinary sized streams is generally 0.88, that is the mean velocity of the current for each vertical will equal the mid-depth velocity multiplied by 0.88.

Sediment Observations.

In making a survey of a silt-bearing stream it is often necessary to determine the nature and extent of the sediment that is carried in suspension in the water. While sediment observations may properly be considered as being rather beyond the scope of Hydrographic Surveying, it is thought advisable to include a brief explanation of the subject in this Manual. Considerations of turbidity, color, etc., which are of interest chiefly to the sanitary engineer, will not be treated; only the method of determining the quantity and the nature of the sediment and its effect upon the physical characteristics of streams will be considered.

The sediment or silt carried in suspension by the water of a river or stream often has an important bearing upon the regimen of the stream. The finer and lighter particles of silt, possessing a specific gravity of unity, are subject to the slightest action of the current and, unless caught in some stagnant place, will be carried to the mouth of the stream. The heavier particles, as the current is checked at some bend or by some obstacle, find lodgment in various places and form shoals, sand bars, islands, etc.

The character and volume of this water-borne material will vary according to the stage of the water and also at different depths in the channel. Sediment observations require that samples of the water be obtained, the percentage of sediment determined in each sample, and the sediment found therein weighed to find its specific gravity. The samples of water should be collected from different parts of the cross-section and at different depths, especially near the surface, and at or near the bottom. Samples from intermediate depths should also be taken if required. The period of collection and of observation should extend over as long a time as may be considered necessary.

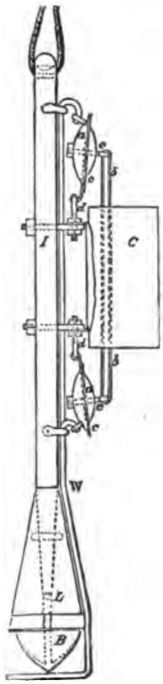

Fig. 99. Hydrophore.

Water samples should be collected daily during this period. Several forms of apparatus have been devised for collecting samples of water at the exact depths required. Perhaps the most convenient apparatus of this kind is that designed by the late Prof. J. B. Johnson and used by him in sediment observations on the Mississippi River. Such an apparatus, which is called a hydrophore, is illustrated in Figure 99, which is taken from Johnson's Surveying. By its use samples of water can be obtained at any desired depth and brought to the surface exactly as secured.

The various samples should be placed in closed glass jars; on each jar should be a label containing the date the specimen was obtained, the depth from which it was taken and such other information as may be necessary. The specific gravity of the sediment in a sample may be determined by straining through filter paper, which should be weighed before use, and dried and re-weighed to determine the weight of sediment contained on it. The volume of the sample should be noted before straining. From the data thus obtained the percentage and weight of the silt carried in suspension at any required depth can be ascertained.

HYDROGRAPHIC SURVEYING.

INDEX.

INDEX TO ILLUSTRATIONS.

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